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Marjorie Lundquist, Ph.D.
Bioelectromagnetic Hygienist
P. O. Box 11831
Milwaukee, WI 53211-0831

marlundquist@usa.net

May 25, 2005

Marlene H. Dortch, Secretary
Federal Communications Commission
Office of the Secretary
445 – 12th Street, S.W.
Washington DC 20554

WT Docket No. 04-435
Use of Cellular Phones Aboard Airplanes in Flight

Dear Sirs:

I cannot speak to the question of whether the use of cellular telephones on an airplane in flight will interfere with electronic operation of the aircraft because I have no information on this issue.

I understand that in the past, the Federal Communications Commission (FCC) banned the use of cellular telephones on aircraft during flight as a safety measure, because of the possibility of such interference (which could, in principle, have caused the airplane to crash, if such interference had been disruptive of information flow critical to safe operation of the airplane).

My comments in this submission will address a slightly different safety issue: whether the use of cellular phones on an airplane in flight may pose a threat to the health and safety of those biological entities collectively termed "airplane crew members" and "airplane passengers".

I want to emphasize that my comments will ***not*** address the ***etiquette*** of cellular phone use on an airplane in flight! My comments are concerned ***solely*** with issues of ***health*** and ***safety*** associated with the use of cellular telephones aboard an airplane in flight. In Appendix A, I enclose new information not previously available to any federal agency which is relevant to the evaluation of the healthfulness of cellular phone use, and to the possible safety hazards that the use of cellular phones on board an aircraft in flight may pose. This new information consists of a paper orally presented by me at the March 2005 meeting of the American Physical Society in Los Angeles, CA.

People who use a cellular telephone with an antenna in the handset expose a portion of their brain tissue on one side of their head to the microwave field that surrounds the antenna of their cellular phone. In fact, their head is so close to the antenna during use of the cellular phone that a portion of their brain is exposed to the ***near field*** of this transmitter.

According to existing voluntary consensus standards (e.g., ANSI C95), exposure of their brain to this microwave field generated by the cellular phone antenna is safe. But suppose it could be shown that existing voluntary consensus standards for exposure to microwave radiation are ***inadequate*** to ensure the health and safety of a cellular phone user?

In that case, a passenger using a cellular phone while sitting in his or her seat on the airplane—unless he or she were occupying a window seat and were using the phone on the side of the head by the window—would find it impossible to avoid exposing one other passenger to the field around the antenna of the cellular phone, because passengers are squeezed so close together in today's airline seats that each person's head is close to the head of his or her seatmate.

Current health protection standards, such as ANSI C95 (and others), have been developed to protect against the heating effects that occur when electromagnetic energy is absorbed by matter, including living tissues. But physicists have known since 1909 that non-ionizing electromagnetic interact with matter in ***three different ways***:

- by transferring some of the energy of the electromagnetic field to the matter;
- by transferring some of the linear momentum of the electromagnetic field to matter; and
- by transferring some of the angular momentum of the electromagnetic field to matter.

The first interaction above is the one that electrical engineers are familiar with. It represents a ***thermal*** hazard to health.

The other two represent ***nonthermal*** hazards to health. Of these two, the transfer of angular momentum is the more hazardous, because it imposes a torque—a twisting force—on matter. In living tissues, this produces very destructive local effects indeed: it rips tissues apart!

Our society has developed a health-protective standard for just ***one*** of these interactions. At this time, we have ***no protection at all*** against the other two!

The FCC is currently relying on a limit of 200 microwatts/cm^2 to protect the populace of this country. This probably derived from the paper by Daniel Cahill (an employee of the U.S. Environmental Protection Agency) cited below. This limit will protect against a ***thermal*** hazard to health, but ***not*** against ***either of the nonthermal hazards!***

It is within the power of the FCC to provide such protection to the passengers and crew of airplanes in flight. All that needs to be done is to ***continue the ban*** against the use of personal cellular phones aboard airplanes in flight!

Sincerely,

Marjorie Lundquist

Marjorie Lundquist, Ph.D.
Bioelectromagnetic Hygienist

Daniel F. Cahill. A suggested limit for population exposure to radiofrequency radiation. Health Physics 45(1):109-126 (July 1983).

Appendices A and B and C accompany this submission and are part of it.

APPENDIX A

Psychological and behavioral effects of microwave radiation

Marjorie Lundquist
May 25, 2005

At the mid-point of the twentieth century, the Soviet Union and a number of countries of eastern Europe, including Poland and Czeckoslovakia, possessed most of the world's knowledge regarding the health effects on human beings of chronic exposure to microwave radiation that was low by the first voluntary consensus standard in the USA for human exposure to such radiation—ANSI C95 (1966)—which established an upper limit of 10 mW/cm^2 to the radiation power density. (This standard was frankly based on the heating effect of irradiation by a plane electromagnetic wave.)

By establishing this value, the United States signaled to the rest of the world that it did not, at that time, recognize the validity of the reports from the Soviet Union and Eastern Europe of the "neurasthenic syndrome" which was observed primarily in people who worked in the vicinity of microwave transmitters. The symptoms included headache, loss of appetite, drowsiness, fatigue, irritability, emotional lability, memory problems, difficulty in concentrating, depression, enlargement of the thyroid gland and sweating.

One physician in the USA became concerned about the health hazards of microwave radiation to workers in this country: John T. McLaughlin, who was providing medical services under contract to the Hughes Aircraft Corporation of Culver City, California, a defense contractor that, during and after World War II, was manufacturing and supplying radar systems to the U. S. Navy's Bureau of Ships.

In 1952 a Hughes Aircraft employee was taken to the hospital suffering from internal bleeding. A hospital spokesman told Dr. McLaughlin that the man's condition resembled a case of mild radiation poisoning, and suggested that Dr. McLaughlin look into it. Dr. McLaughlin took the suggestion to heart and began a survey of Hughes Aircraft employees, uncovering many more cases of internal bleeding, many complaints of headache, brain cancer in three members of a five-man research team, and reports of cataracts, to list only a few of his findings.

He prepared a report[1] for Hughes Aircraft executives early in 1953 titled "A Survey of Possible Health Hazards from Exposure to Microwave Radiation". With the approval of the corporation executives, he sent a copy of his report to the Pentagon, which was so alarmed that it convened a meeting later that spring with the objective of establishing a "safe level" of exposure to microwave radiation to protect U.S. servicemen. On the assumption that the only threat to human health was a thermal effect—that is, the generation of more heat in body tissues than could be dissipated via the body's thermoregulatory mechanisms—consensus at the meeting on a value of 100 mW/cm^2 was reached; but one of the meeting attendees—Herman Schwan, a biophysicist who was born and educated in Germany—wrote a memo to the Bureau of Ships suggesting that a better value was 10 mW/cm^2 because it offered a greater margin of safety. The various military branches adopted this value by executive order rather rapidly. [After a good deal of research on animals, this was adopted (in 1966) as a consensus value by the committee in charge of ANSI C95.]

However, in 1957 Dr. McLaughlin published an alarming paper[2] in a medical journal reporting the death of a Hughes employee, attributing it to this man's accidental exposure to a low-intensity microwave beam from a new, high-power experimental radar unit.

The Pentagon was not pleased. The public was already concerned about possible health effects of exposure to radar, which was absolutely essential to the nation's defense. Publication of the medical report that Dr. McLaughlin had written was like throwing gasoline on a fire! It would further alarm the public, thereby creating public relations problems for those branches of the military that needed to erect radar stations for the nation's defense in populated regions of the country. A "stealth" campaign to discredit Dr. McLaughlin and his concern regarding the harmful effects of exposure to microwave radiation was begun. Probably pressure was put on Hughes Aircraft Corporation not to renew the company's contract for Dr. McLaughlin's medical services because after one more paper by him was published[3] in 1962, nothing more from him appears in the medical literature.

In the late 1960s and the 1970s there was renewed interest in the issue of non-ionizing radiation health hazards. By this time some epidemiological studies had been carried out. A medical doctor named Charlotte Silverman worked for the Bureau of Radiological Health, which was situateed within the U.S. Food and Drug administration; she authored several reports[4,6] reviewing epidemiological studies of the health effects of microwave radiation on human beings. Here is a quotation from a section of the latter report headed "Nervous and Behavioral Effects":

"The many clinical and laboratory studies from the USSR and other Eastern European countries provide important information but no firm evidence of specific microwave effects on neurologic, mental, or behavioral performance.[ref. del.] Clinical studies of groups employed in the operation, testing, maintenance, and manufacture of microwave-generating equipment have involved mainly low-level (microwatts or a few milliwatts) and long-term exposures. With few exceptions, functional disturbances of the central nervous system have been described as a typical kind of radiowave sickness, the neurasthenic or asthenic syndrome. The symptoms and signs include headache, fatigability, irritability, loss of appetite, sleepiness, sweating, thyroid gland enlargement, difficulties in concentration or memory, depression, and emotional instability. This clinical syndrome is generally reversible if exposure is discontinued. Another frequently described manifestation is a set of labile functional cardiovascular changes including bradycardia (or occasional tachycardia), arterial hypertension (or hypotension), and changes in cardiac conduction. This form of neurocirculatory asthenia is also attributed to nervous system influence. More serious but less frequent neurologic or neuropsychiatric disturbances have occasionally been described as a diencephalic syndrome."

Notice that symptoms of "radiowave sickness" she listed included "irritability" and "emotional instability", sometimes referred to as "emotional lability", meaning that the person's emotions change rapidly. It is my belief that the phenomena of "road rage" and "air rage" that arose in the late 1990s are the result of the many people in our society who now have microwave-irradiated brains due to the use of wireless phones, and consequently are displaying the irritability and emotionality that result.

A syndrome variously termed "microwave sickness" or "radio-frequency radiation sickness syndrome" was first described by physicians in the former Soviet Union and Eastern bloc countries in the early twentieth century. Scientists and physicians in the Western Hemisphere have been skeptical that this was a real phenomenon since the 1950s, and refused to accept its existence throughout most of the twentieth century.[9] But now this is changing.

Between 1953 and 1976, the U.S. embassy in Moscow was irradiated with low-intensity microwave radiation by the Russians. The Lilienfeld study, done at Johns Hopkins University, collected medical data on Foreign Service personnel who worked there, and also collected exposure data.[5] In 1998 Ana Johnson Liakouris reported the first investigation ever conducted on these data with respect to this syndrome, concluding that the available data support the claim that "RF sickness" is a true medical syndrome.[12]

Three years later Bruce Hocking, the Australian physician who has done so much, reached the same conclusion quite independently.[14] He did not cite the paper by Ana Johnson Liakouris, so he probably had not read it. He noted that a paper by Forman *et al.*,[8] published in 1982, included a report of microwave sickness. (Forman *et al.* had noted that a case report[7] published in 1980 was similar in several respects to the one they were reporting.) It began to be apparent that microwave sickness has been here in the USA for quite a while, without being recognized!

Santini *et al.*[13] assert that radiofrequency sickness has been reported in association with microwave exposure to the fixed transmitter of a wireless phone system—called a "relay station" in France, and a "base station" in the USA. Another paper[15] indicates that, in France, the symptoms of microwave sickness can be found in people who live within 100 meters (~300 feet) of a wireless phone base station, with more detailed information being published[16] about a year later.

Now that many countries are subjecting their entire populations to long-term exposure to low-intensity microwave radiation by allowing wireless telephone service to be provided within their boundaries, the human population in the Western Hemisphere that is experiencing such exposure has become sufficiently large that this syndrome is being observed in Western bloc countries, including the USA. And since this syndrome includes mental and emotional symptoms, which seem to occur especially when the individual is close enough to a microwave transmitter to be in or on the fringes of its "near field", it seems likely that the only way to reduce the incidence of the mental and emotional symptoms in the populace is to reduce its exposure to microwave radiation—especially to the near field of a microwave source, the most common of which is a cellular phone!

Therefore, if we don't want a planeload of people who are behaving in an unruly manner that may endanger their fellow passengers or members of the crew, it would be prudent to ensure that their brains are ***not*** exposed to microwave radiation from their use of their personal cellular telephone while they are on board an airplane in flight! Hence the Federal Communications Commission should continue its ban on the use of personal cellular phones in flight.

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Clinical Medicine

Exposure to radio-frequency radiation from an aircraft radar unit

ROBERT A. WILLIAMS and THOMAS S. WEBB

Aeromedical Services, USAF Regional Medical Center Clark, Clark Air Base, Republic of the Philippines

WILLIAMS, R. A., and T. S. WEBB. *Exposure to radio-frequency radiation from an aircraft radar unit.* Aviat. Space Environ. Med. 51(11): 1243-1244, 1980.

Two airmen exposed to radio-frequency radiation 38 times above the Air Force permissible exposure level were medically evaluated for physical effects from exposure. Initial anxiety and hypertension were found, but these problems resolved with therapy. This case is reported with the hope that further research will be undertaken to understand the behavioral effects of radar beams on exposed aircrew or ground personnel.

RADIO-FREQUENCY radiation or microwaves are a form of nonionizing electromagnetic radiation. They are generally considered to include wave lengths from 0.001-2 m long. Military and commercial aircraft communications and navigation aids are within these frequencies. The extensive increase in the use of microwave devices will invariably result in increased human exposure (1-6). The following case report describes the exposure of two aircraft maintenance men to radio-frequency radiation.

Two Air Force flight mechanics stationed at Clark Air Base, Republic of the Philippines were exposed to radio-frequency (RF) energy at a level approximately 38 times above the Air Force permissible exposure level (PEL).

Three flight mechanics were dispatched to perform minor maintenance work on an F-4 aircraft. One was a supervisor and, since the workload was light that night, he intended to use this particular evening for some additional on-the-job training for two junior mechanics. The following is a scenario of events as told by the supervisor:

"We proceeded to the aircraft and set up our test equipment, hooked up air-conditioning, and opened up the radome (fiberglass covering for a radar antenna). Upon opening the radome, we immediately discovered some switched cables. We corrected this discrepancy, applied power to the aircraft and our system operational check equipment. I asked one airman to run the radar while I taught the other how to run the APX-80 test set. Our test set was set up approximately 8-10 feet in front of the radar antenna. This distance was restricted (dictated) because of vehicular traffic and length of ground and power cords. We made a quick radar check and then proceeded with the APX-80 check. We were standing in front of the radar operating the test set when, after about 20 minutes, I noticed that the scope presentation was good but not according to Air Force Technical Order specifications. I then put my left arm right in front of the radar antenna to check our dipoles with a light bulb. It was then that I felt the RF heat coming from the antenna. I climbed up to the rear cockpit and checked the radar setting. It was in standby like it was supposed to be. I turned the radar meter select switch to monitor the magnetron and discovered that the magnetron was firing."

Characteristics of the radar unit: Type—AN/APO 120; Frequency—greater than 10 GHz; Mode—continuous wave; Peak power at time of exposure—200 W.

The exposure situation was recreated and measurements were made of the RF power density by the Hospital Bioenvironmental Engineer. A Narda Model 8300 RF survey meter was used to measure and define the field. Measurement of the RF energy was made at 10-ft intervals beginning 80 ft from the aircraft and working inward. At 10 ft from the radar antenna, the limit (100 mW/cm^2) of the survey instrument was exceeded. The 20-ft measured level was used as a base and exposure levels in the working area of the flight mechanics were calculated. At 6.5 ft, where they stood for 20 min, the RF level was found to be 379 mW/cm^2, at 1 ft (15-30 s exposure) 16,000 mW/cm^2. The major portions of the head and trunk of both individuals were in the main beam during the entire exposure incident. The third mechanic was not exposed to the microwave radiation. His position during the maintenance was not within the range of the radar beam.

The supervisor was the only one of the two flight mechanics exposed during the described incident who reported to the Flight Surgeon Office for physical evaluation. And this was 7 d post-exposure. Immediately after the primary exposure, the supervisor felt a warm feeling on his left side, neck, and head. He described a warm feeling just like a minor sunburn. On his initial hospital visit 7 d post-exposure, there was no redness, discoloration, or swelling noted anywhere on his left side. The week after exposure, the patient did suffer from nausea, lightheadedness, and extreme apprehension. The patient denied any clicking sounds in the ears. His normal body weight was 195 lbs. On his initial visit, he weighed 176 lbs. His appetite had been very poor the past 8 d. The flight mechanic supervisor's chief complaint on admission was photosensitivity. Sunlight made him very uncomfortable. His past medical history and family history were unremarkable. Review of systems was negative. On physical examination, his blood pressure was 164/110 (sitting) bilaterally measured. He was very apprehensive. It was felt at the time of the physical that the cause of his elevated blood pressure was anxiety and apprehension. He had no previous history of hypertension but did have a family history of mild hypertension. His blood pressure remained slightly elevated during 4 d of hospitalization. During his hospital stay, his apprehension improved daily as negative findings were reported. Neurological and ophthalmological evaluations were completed during his hospitalization. There was no evidence of neurological disease. Ophthalmological consultation found normal bilateral 20/20 vision. No disease was found. Visual fields and photographs of his eyegrounds were completed for future reference. The sergeant was returned to full duty after 2 weeks of vacation. He was followed up on a monthly basis by the Aeromedical Services staff for his hypertension and hypercholesterolemia, which were incidental findings. He quickly returned to the normal recommended levels.

Review of the very scant existing literature on human exposure gave very little information. The aeromedical staff did not know hwat to expect but, in general, the major medical problem was anxiety manifested by loss of appetite. There have been other reported microwave exposures that produced a similar reaction.

This incident was caused by the lack of (3-6) adequate warning information placed in the technical orders. An emergency change was prepared and forwarded to the appropriate Air Force systems manager.

In general, the biological effects on the body vary with the wavelength or frequency. Most radiation energy is easily absorbed depending on the water content of exposed tissue. The body organs least able to dissipate heat are the organs most susceptible to microwave radiation, such as eyes and testicles. Except for the eyes, the sensation of warmth provides a warning mechanism.

Exposure standards in the United States for microwave radiation (10 mW/cm^2 over 0.1 h) are based solely on the heating effects related to wavelength, power intensity, and time of exposure. The longer wavelengths of 100-100,000 MHz will produce a greater temperature rise than the shorter ones. The Soviet Union and its satellite countries for over 10 years have used more stringent standards of 1-2.5 mW/cm^2 that include shorter wavelengths (low energy) which produce no heating. These "athermal" effects, the USSR reported, included headaches, fatigue, and behavioral changes in humans and animals (3).

This exposure confirms the need for further study of the behavioral effects of radar beams on aircrew or ground personnel. System interlocks, protective clothing, and shields are still imperative requirements for workmen servicing radar units. Research currently is underway to develop field equipment that will measure and warn immediately of hazardous power density fields.

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Case Report

Psychological Symptoms and Intermittent Hypertension Following Acute Microwave Exposure

LCDR Samuel A. Forman, MC, USNR; CDR Christopher K. Holmes, MC, USNR; CAPT T. V. McManamon, MC, USNR; and LCDR William R. Wedding, MSC, USN

Two men who were accidently, acutely irradiated with X-band microwave radiation have been followed up clinically for 12 months. Both men developed similar psychological symptoms, which included emotional lability, irritability, headaches, and insomnia. Several months after the incidents, hypertension was diagnosed in both patients. No organic basis for the psychological problems could be found nor could any secondary cause for the hypertension. A similar syndrome following microwave exposure has been described by the East Europeans. The two cases we report, with comparable subjective symptoms and hypertension following a common exposure, provide further strong, circumstantial evidence of cause and effect. A greater knowledge of the mechanisms involved in bioeffects which may be induced by radiofrequency and microwave radiation is definitely needed.

Radiofrequencies in the microwave range are used in various applications from food production to medical diathermy. Recent uses in communications, radar, and power transmission are notable for greater power and range than had been permitted by the technology of just a few years ago. Reported injuries due to acute microwave exposure are few, but we report the following two cases.

The two cases involved men on military field maneuvers operating a portable high-power microwave radar tracking system. Separate accidental exposures occurred when the men were inadvertently radiated during the system's operation. They were lightly clothed in military fatigue uniforms and hats. Ambient temperature at the time of the exposure was approximately 18 °C, and the relative humidity was approximately 50%.

The two men sustained their accidental exposures on successive days while facing a fire-control radar that operates in the X-band frequencies. The exposures occurred in the radiating near field (Fresnel region) and were from a continuous wave beam from a uniformly illuminated, circular aperture antenna. The worst case of field strength parameters, determined by calculation and follow-up field survey, showed an electric field strength of $|E| = 475$ to about 580 V/m, which corresponds to an equivalent plane wave power density of 60 to 90 mW/cm^2, with the most probable electric field strength on the order of 580 V/m. (The primary reason for the difference in the exposure values is due to the uncertainty in distance between the exposed personnel and the antenna.)

Exposure standards used by the Navy are based on current standards of the American National Standards Institute and are 10 mW/cm^2 for exposure times greater than six minutes. For exposures less than six minutes, the exposure limit is based on power density, in mW/cm^2 of $1/T$, where T is in hours, with a maximum exposure of 100 mW/cm^2 for an exposure time of .01 hour.

Report of Cases

Case 1 – A 54-year-old man in good health was exposed continuously for 80 s to the electromagnetic field. At the time of the incident, he reported severe chest pain, vertigo and a heating sensation of the chest and head. Facial erythema persisted for three days. Postprandial stomach cramps, dysphagia, shoulder soreness and gritty eye sensations occurred within the first day and persisted for several weeks.

He also experienced rapid onset of recurrent, severe headaches, some of which were preceded by scintillating

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From the Naval Regional Medical Center, Long Beach, Calif. (Dr. Forman, Occupational and Environmental Health Service); the Naval Regional Medical Center, San Diego, Calif. (Drs. Holmes and McManamon, Environmental Health Service; Mr. Wedding, Department of Radiology).

Dr. Forman's present address is Navy Environmental Health Center, Norfolk, VA 23511. Address correspondence to Dr. Forman.

The opionions or assertions expressed herein are those of the authors and are not to be construed as official or as reflecting the views of the Department of the Navy or the naval service at large.

scotomata; insomnia; irritability; and emotional lability. Psychological symptoms led to disruption of work and family life. Peak severity of the subjective complaints occurred three months after the exposure, coincident with the diagnosis of arterial hypertension in the range of 160/105 mm Hg.

Extensive inpatient medical, ophthalmologic, endocrine and psychiatric evaluations were performed five months after the episode. No secondary cause of hypertension was discovered. No lenticular opacities were found. Neurologic examination, EEG and brain scan were normal. No evidence of organicity was detected on psychological testing, which included the Wechsler Memory Quotient, Reitan Battery, and the Thematic Interpretation Test. Psychiatric interviews, the Minnesota Multiphasic Personality Inventory, and Rorschach tests revealed depression and emotional liability. A diagnosis of acute postraumatic stress disorder was given.

Blood pressure was initially controlled with daily doses of 50 mg of traimterine and 25 mg of hydrochlorothiazide. Blood pressure readings remained in the normal range after withdrawing medication following one month of therapy.

Psychological problems have been of varying severity over a year of follow-up. There have been several hospitalizations for supportive therapy of these complaints, but a lasting remission has not been achieved.

Psychological testing repeated 12 months after the incident revealed evidence of moderate left parietal cerebral cortex dysfunction on the Reitan Battery. Repeated neurologic examination, including EEG, brain scan, and computed axial tomographic scan could not confirm an organic central nervous system disorder. The neurologic evaluation remained within normal limits.

Case 2 – A 21-year-old healthy man sustained intermittent exposure to the microwave beam over a period of five minutes (Total time of irradiation was approximately 75 s). Immediate effects included a heating sensation of his chest and head and a headache. He reported erythema of his chest and face lasting one day. A creatine phosphokinase determination was 2,560 units two days later but promptly returned to normal limits within 72 hours.

In the period since the exposure, the patient has described nondisabling irritability, insomnia, headaches, photophobia and visual blurring. Four months after his exposure, hypertension of 140/105 mm Hg was detected.

An extensive inpatient workup discovered no organic cause for the hypertension, visual disturbances or psychological complaints. Psychiatric interviews and psychological testing yielded inconsistent results. A diagnosis of post-traumatic stress disorder was assigned.

Hypertension was clinically evident and controlled with daily doses of hydrochlorothiazide for three months after the incident. Blood pressure readings have remained in the normal range during the remainder of the 12-month follow-up. The patient reports continuing emotional lability and insomnia. Subjective symptoms have been mild and have not required therapeutic intervention.

Two other healthy men, aged 30 and 39 years, were each exposed once during this incident to the same microwave power density for 5 to 10 s. They both reported headaches, vertigo and a heating sensation. One noted headache and eructation persisting for 10 days. The other reported lethargy, decreased attention span and forgetfulness for three weeks. Neither have long-term pathologic symptoms or signs. No abnormalities were found among blood count, serum electrolyte levels, multiphasic serum screening or slit-lamp examinations.

Comment

Microwaves encompass a portion of the electromagnetic spectrum between television radiofrequencies and infrared light, corresponding to wave lengths from 3 m to 3 mm. Energy quanta of the microwave region are insufficient to cause molecular ionization. Consequently, their effects on biological systems have most often been attributed to heat-induced polar protein denaturation and water molecular vibration.[1]

A number of radiofrequency and microwave absorption studies have been done using poly-gamma-benzyl-L-glutamate (PBLG) and indicate frequency-dependent mechanisms, such as overall rotation of the compound's helical structure, group rotation of its side chains, chemical relaxation, quasilattice vibrations and X-H. . .Y vibrations.[2]

Many Eastern European researchers believe electromagnetic-biological interaction may occur at power levels that do not cause tissue heating. Existence of nonthermal effects remains a controversial issue between eastern and western investigators.[3]

Only scattered reports of acute human exposure are found in the literature. Reports of microwave interference with cardiac pacemakers have resulted in the shielding of newly designed devices.[4] Hypogonadism occurred in a man exposed to a very high level of microwave radiation.[5] While not universally accepted, lenticular opacities have been reported after acute and chronic exposures to microwaves.[6] Thus far, no deaths have been attributed unequivocally to microwave exposure.[7]

The Soviet author Petrov[8] describes an acute, self-limited syndrome of microwave exposure characterized by headache, nausea, vertigo, insomnia, hypertension and cardiac rhythm disturbances. As with most of the East European communications on the subject, the type, circumstances and total exposure of radiation are unspecified in the published reports.

A case reported by Williams and Webb[9] in the English literature described a military radar repairman who experienced anxiety and hypertension following an acute X-band exposure incident. The authors judged that the discovery of elevated blood pressure in this man was coincidental. Their findings, however, take on a greater significance when compared with the cases we report. Both incidents (ours and theirs) involve psychological symptoms and hypertension following acute, high-level exposure to centimeter wavelength microwaves.

The Soviets and Poles recognize a microwave radiation sickness or "neurasthenic syndrome" as a result of chronic exposure.[10] Progressive stages are characterized, beginning with subjective symptoms of headache, excitability and fatigue. Objective findings include labile blood pressure and cardiac arrhythmias. Severely affected workers are said to exhibit characteristic EEG changes indicative of diencephalic disturbances.[11] "Microwave radiation sickness" has not been reported in the western scientific literature and is widely discounted.

Conclusion

We report two cases with similar subjective symptoms and hypertension following accidental, one-time exposure to microwave radiation. The possibility of microwave causation in these cases is suggested by the almost synchronous independent development of symptoms and signs in healthy individuals sharing a common exposure. Similarity to reports chiefly by East Europeans of syndromes related to acute and chronic microwave radiation exposures is striking. Despite circumstantial evidence of cause and effect, no organic basis was discovered for the complaints. Posttraumatic stress remains a likely explanation of the subjective symptoms. The many factors that potentially confound establishment of causality for environmental exposures prevent firm conclusions from being drawn in these cases.

Complete knowledge of the biological effects of microwave radiation remains an elusive goal. Animal research and close characterization of human exposures should continue in order to fill gaps in present knowledge.

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The Robe of Loneliness

There is a unique loneliness in being a medical student, and it is a vital forerunner of the aloneness that follows into later years. It is not all that unpleasant, merely a sense that there is a world into which you are being drawn, and to which you cannot bring even your nearest and dearest. It is a fundamental separation, in which books, facts, learning processes, and experiences become close companions, and the friends of before recede somewhat.

I'm not sure why I refer to this loneliness as acquired. I guess on some level I do see it as a robe that must be picked up, put around one's shoulders, and made one's own by a very active process. Loneliness doesn't just *happen* to you by a passive osmosis. It is something you work at in some crazy way. It is also manifest in sudden, veiled ways.

You are aware of it the first time you see or do something that upsets you, and you feel instinctively that this is something you must deal with without sharing it. Perhaps you sense that the subject is taboo in ordinary conversation, or it is something that others will just not want to hear. Perhaps you are wrong, but something says, "Spare your friend. Don't tell her. She wouldn't understand, nor is it necessary for her to understand. First try to understand it yourself." As I said, perhaps you were wrong. Your friend may be sensitive to your distress and want very much to discuss it with you. But your judgment is not what concerns us here, only the voice that tells you to maintain your silence. It is very real.

— From *So You Want to be a Doctor? — The Realities of Pursuing Medicine as a Career* by Naomi Bluestone, M.D., New York: Lothrop, Lee & Shepard Books.

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Results of our 15-year study into the biological effects of microwave exposure.

Djordjevic Z, Kolak A, Djokovic V, Ristic P, Kelecevic Z.

The results obtained during 15 years of clinical and experimental examinations of biological microwave exposure effects are briefly surveyed. Some important results are reported. Based on their experience, the authors present their attitudes concerning harmful microwave effects on living matter. They consider that microwave effects, either direct or indirect, are the results of hyperthermia. Exposure of the living body to irradiation intensities not causing thermal effects do not induce important pathological alterations in the irradiated organisms. Also, it has been pointed out that the term "injury" is more suitable than the term "microwave sickness" when harmful effects of microwaves to the living organism are concerned. According to the authors, the term "microwave sickness" is not acceptable as a synonym for professional diseases of persons working with sources of microwave energy, since it refers to the complex of insufficiently defined symptoms of uncertain etiology.

group. We are now able to provide further information.

Study.—On completion of the double-blind part of the study, most patients continued taking lovastatin in an open extension of the study, which is ongoing. With the exception of two patients who moved to other states, the 13 patients who had new lens opacities reported are still taking lovastatin. All these patients have had between four and six complete ophthalmologic examinations; by the time of the last examination, the patients had taken lovastatin for an average of 26 months. Eleven of these patients are men (mean age, 60 years on entry into the study) and two are women (mean age, 65 years). In all cases, the newly reported opacities were located in the cortex of the lens, and in one patient nuclear sclerosis also was reported. Four patients had a one-line decrease in corrected visual acuity from baseline to the last examination and two patients had a one-line improvement in one or both eyes. (A one-line change is well within the margin of error of the measurement.) There is thus no evidence that lovastatin therapy adversely affected the vision of any of these patients. If lovastatin treatment had caused the initial appearance of these opacities after a period as short as the 12- to 18-week treatment duration of the original study, progression to the point of causing visual loss would be expected in some if not in all of these 13 patients now that their drug exposure is five to ten times longer. As discussed elsewhere,[2] it is likely that small opacities were present but missed at baseline. This is supported by the fact that in another much larger group of patients there was no increase in prevalence of lens opacities among 431 patients treated with lovastatin for five to 15 months (baseline prevalence, 34.1%; posttreatment prevalence, 31.6%) (Lovastatin [Mevacor], package insert, Merck Sharp & Dohme, West Point, Pa).

In conclusion, we believe that there is no evidence to date from our study or any other study that lovastatin therapy has any adverse effect on the human lens. Nevertheless, until further experience is obtained, the manufacturer of lovastatin recommends baseline and annual slit-lamp examinations as a precaution (Lovastatin [Mevacor], package insert, Merck Sharp & Dohme, West Point, Pa).

Donald B. Hunninghake, MD
Valery T. Miller, MD
Ira Goldberg, MD
Gustav Schonfeld, MD
Evan A. Stein, MD, PhD
Jonathan A. Tobert, MB, PhD
The Lovastatin Study Group II

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Sublethal Exposure to Microwave Radar

To the Editor.—Injuries resulting from exposure to microwave radiation are rare and usually occur in association with the use of microwave ovens. Both accidental and intentional (resulting from child abuse) injuries have been reported.[1,2] Microwaves are also used in industrial applications and in our national defense. For example, radar transmitters in the F-16 jet fighter operate with frequencies within the microwave spectrum. We briefly describe a rare case of accidental exposure to this type of radiation from an airplane radar system in which the patient survived.

Report of a Case.—A 42-year-old male pilot inadvertently stood in front of a functioning microwave airfighter radar system for approximately five minutes. At that time, a moderate sensation of heat was perceived in the head and neck. The following morning while shaving, the patient noticed a small, tender lump in the lower right aspect of his neck. This mass continued to enlarge and to cause discomfort. A month later, he consulted a physician and a thyroid radionuclide scan was performed, which was read as negative. During the following month, the patient subjectively noted loss of recent memory, extreme sleepiness, and persistence of the neck mass. A computed tomographic scan demonstrated prominence of the soft tissues extending from the region of the base of the tongue to the epiglottis bilaterally. There was edema and a 1.2-cm homogenous solid mass in the region of the right vallecula. Thickening of the aryepiglottic folds and of the false and true vocal cords also was noted. The right sternocleidomastoid muscle showed a 3 × 3-cm area of low density in its lower aspect. While the patient was under general anesthesia, biopsy samples of the lesions in the base of the tongue, the right true vocal cord, and the right sternocleidomastoid muscle were obtained. Microscopic examination revealed interstitial edema and coagulation necrosis consistent with thermal injuries in all three specimens. The patient continued to complain of loss of memory; a magnetic resonance scan of the brain was normal.

Comment.—Only one case similar to this one has been described, to our knowledge.[3] In that instance, the patient died as a consequence of severe bowel destruction following exposure to microwaves from a radar system. We have no explanation for the neurological findings our patient experienced, but during the last four months, his memory has improved. Personnel who come in contact with devices that produce microwave radiation should be aware of the potential hazardous effects resulting from their use and should take appropriate safety precautions.

Mauricio Castillo, MD
Robert M. Quencer, MD
University of Miami School of Medicine/
Jackson Memorial Medical Center

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Listing of Combined Internal Medicine and Pediatric Residencies

To the Editor.—In reviewing the Aug 28 EDUCATION ISSUE of *JAMA*,[1] I saw that there was no mention of the residency programs in combined Internal Medicine and Pediatrics. These residency programs were approved by a joint agreement between the boards of Internal Medicine and Pediatrics in 1967.[2] Since that time, the number of formal programs has risen to 77,[3] creating approximately 200 internship positions each year. Although these programs do not receive separate review by the American Council for Graduate Medical Education, the boards of Internal Medicine and Pediatrics are now considering closer inspection of the requirements of this training. It was not clear in the Aug 28 issue of *JAMA* if residents of combined Internal Medicine/Pediatrics were included in the statistics or, if so, in which category. Another training program that combines two fields (General Preventive Medicine/Public Health) is listed, as are several residencies that have fewer residents. Data on the number of combined Internal Medicine/Pediatric residents could be easily obtained from the program directors.

In an initial study of graduates of combined Internal Medicine/Pediatrics programs, Greganti and Schuster[4] found that most of the graduates were practicing clinical medicine in both specialties. Therefore, such graduates cannot be considered to be in only one or the other of the fields. Despite the fact that the combined Internal Medicine/Pediatrics programs are a relatively recent addition to postgraduate training, the numbers of such programs has risen dramatically. Graduates of these programs and others are working to define new roles in clinical and academic medi-

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In Reply.—We appreciate the comments by Tilkian et al regarding our finding of elevated serum and red blood cell folate levels in early HIV infection. We, too, considered vitamin B_{12} deficiency and the vitamin B_{12}–folate trap as a possible cause of the apparent elevation of folate levels.[1] However, there was no significant correlation between folate and serum vitamin B_{12} levels in our patients ($r = .12$; $P = .51$). While approximately 25% of our patients were vitamin B_{12} deficient, they were not consistently the same subjects with the elevated folate levels (Figure). Consequently, an alternative explanation should be sought.

As pointed out by Tilkian and coworkers, cellular lysis might result in transient elevation of serum nutrient levels. However, our patients had elevated levels of both serum and, most notably, erythrocyte folate. Therefore, release of intracellular folate alone cannot explain our findings. The binding of folate to serum protein(s) is certainly a possibility. Human immunodeficiency virus infection may result in an alteration of the specific folate-binding proteins,[2] or of other proteins such as acute-phase reactants, which may surreptitiously bind folate. It has been shown that riboflavin, another B vitamin, is bound to immunoglobulins[3]; it is possible that if folate is similarly bound, the hypergammaglobulinemia observed in the HIV-infected patient may explain the elevated folate level. The biologic availability of such protein-bound folate compounds for cellular metabolism may be limited; we are presently attempting to establish what fraction of this elevated folate is available for cellular processes such as DNA synthesis. As noted in our initial correspondence, the precise form of this folate may be of clinical significance, as many of the opportunistic pathogens that affect the HIV-infected patient are treated with antifolate agents.

The phenomenon of chromosome fragile-site expression in HIV infection is most intriguing and folate status in the HIV-infected patient should be investigated. With the wide range of changes that occur in nutriture and metabolism in HIV infection, it may prove difficult to isolate the role of folate per se in such fragile-site expression. Appropriate in vitro studies, employing folate supplementation of cultured HIV-infected lymphocytes, should assist us in this process. However, use of fragile-site expression as a measure of folate status should await this necessary documentation.

Finally, a recent report[4] must be noted in conjunction with these findings of altered folate metabolism in the HIV-infected patient. A gene for the enzyme dihydrofolate reductase has been found in two types of herpesviruses—herpesvirus samiri and herpesvirus ateles. We would like to suggest the possibility that the HIV-1 virus may carry similar DNA sequences and may thereby alter the folate metabolism of its human host.

Richard S. Beach, MD, PhD
Emlio Mantero-Atienza, MD, MPH
Carl Eisdorfer, MD, PhD
Marianna K. Fordyce-Baum, PhD
University of Miami
School of Medicine

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Sublethal Exposure to Microwave Radar

To the Editor.—I read with interest the letter by Drs Castillo and Quencer[1] that describes a 42-year-old man with coagulation necrosis of the vallecula and the sternocleidomastoid muscle and psychological symptoms following short-term exposure to microwave radar.

The case report describes accidental exposure for five minutes to military radar. There are no data concerning the wavelength, pulse characteristics, and field intensity of the radar source. Just as we expect a case report of a drug overdose to state the pharmacologic agent, the dose, and the route of entry, an adequate description of an environmental microwave exposure includes wavelength, source characteristics (continuous or intermittent), and field intensity. Microwave field intensity is described by both electric field strength (volts per minute) and power density (milliwatts per square centimeter).

Microwaves encompass a range of electromagnetic nonionizing radiation whose energy levels and tissue penetration depend on wavelength. All radar systems, microwave ovens, diathermy machines, and a variety of industrial heat sources produce specific wavelengths of microwave energy to achieve their effects. Microwave energy is not characterized by the inverse square of distance from the emission source as is ionizing radiation, so a radiation physicist must often perform calculations or reconstruct the incident to produce reliable exposure parameters. Exposure data can help the clinician decide whether tissue damage is likely and can increase what we learn from these rare events.

Drs Castillo and Quencer were not familiar with cases similar to their own. I attended four healthy men who were accidentally exposed to a military radar source.[2] The two most severely affected were exposed to an X-band radar for 75s or longer at 475- to 580-V/m electric field strength and 60- to 90-mW/cm^2 power density. A 54-year-old man at the time of exposure had a sudden heating sensation and erythema over the head and chest. In the months following this short-term exposure he suffered headaches, insomnia, irritability, emotional lability, and moderate diastolic hypertension. A 21-year-old man had headaches, irritability, insomnia, photophobia, and moderate diastolic hypertension. In the acute episode he had experienced a heating sensation of the head and chest and a transient elevation of the serum creatine kinase level. Findings from an extensive search for objective central nervous system abnormalities or secondary causes of hypertension were negative. The psychiatric diagnosis in both cases was posttraumatic stress disorder. Another author similarly reported anxiety and hypertension in a 35-year-old man following an X-band microwave incident.[3]

There are scattered reports of other acute microwave health issues. Microwave interference with cardiac pacemakers has resulted in shielding of current devices.[4] Hypogonadism occurred in a man exposed to a very high level of microwaves.[5] Lenticular opacities have been associated with short- and long-term exposures.[6] The attribution of death from microwave exposure referenced by Drs Castillo and Quencer[7] has been discredited subsequently.[8]

Samuel A. Forman, MD, MPH
Cincinnati

1. Castillo M, Quencer RM: Sublethal exposure to microwave radar. *JAMA* 1988;259:355.
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To the Editor.—Drs Castillo and Quencer[1] are to be commended for their letter in the Jan 15 issue of *JAMA*. It details an interesting case report of a radiation injury following a single brief exposure to radar. What is not fully appreciated by our profession is that repeated irradiations at subclinical levels can produce pathology that appears only after delay.

Bowers and Frey[2] reported how the general population is being exposed to an ever-increasing amount of spurious, nonionizing radiation from at least two different sources. The first relates to communitywide broadcast radiation from station transmitters such as radars and earth-satellite telecommunication networks, where achievable power output has doubled with every passing decade. The second relates to nearby personal-use devices such as faulty microwave ovens and video display terminals, which have increased in number exponentially during each decade.

Unlike the rare case of Drs Castillo and Quencer, the vast majority of cases of microwave sickness begin insidiously, as described in the proceedings of the International Symposium of Biologic Effects and Health Hazards of Microwave Radiation.[3]

There, Sadcikova[4] reported her analysis of 100 cases of microwave radiation sickness. Also included is a report by myself[5] that contains a clinically useful classification of microwave sickness into "acute," "subacute," and "delayed" forms based on exposure factors plotted against the time interval before pathology becomes evident.

Drs Castillo and Quencer will, of course, follow up their patient for possible subacute and delayed effects, mutagenicity being the greatest concern.

Interest in microwave-induced chromosomal aberrations began in 1959 when Heller and Teixeira-Pinto[6] published the first report documenting laboratory evidence for mutagenesis.

Becker and Becker,[7] in a detailed case study, analyzed how governmental regulatory agencies responded to such perceived health effects (birth defects and malignancies) at Vernon Township in New Jersey, a site of several earth-satellite telecommunication networks. These authors demonstrated that no agency could deal effectively either with that problem or with any similar problem anywhere else. There is therefore no meaningful, pragmatic method to ensure adequate protection of the general population.

My analysis[8] of newly acquired epidemiologic data implies that the mutagenic potential of nonionizing radiation should now be considered as a factor for the increased prevalence of Down's syndrome in Vernon Township, malignancies in Bourne, Falmouth, and Sandwich—towns that surround the PAVE PAWS radar on Cape Cod in Massachusetts—and the otherwise unexplained increase in breast cancer–related mortality in white women younger than age 50 years, the group most involved with microwave ovens and video display terminals, both usually operated at breast height.

We are indebted to Drs Castillo and Quencer for their detailed case report of a rare, life-threatening acute microwave radiation injury. However, we must become better acquainted with all forms of nonionizing radiation sickness.

Milton M. Zaret, MD
Scarsdale, NY

1. Castillo M, Quencer RM: Sublethal exposure to microwave radar. *JAMA* 1988;259:355.
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In Reply.—Dr Forman states that in our letter we did not specify the parameters of the microwave field to which our patient was exposed. We contacted the Air Force and were informed that this information is considered classified and not available to civilians. We were not aware that Forman and colleagues[1] as well as Williams and Webb[2] had previously described cases similar to ours; we regret this omission. The psychological symptoms that occurred in their patients as well as in our patient were attributed to posttraumatic stress disorder. There is evidence that radar technicians who suffered behavioral changes following exposure to 1 to 10 GHz of radiation demonstrated abnormal band patterns in cerebrospinal fluid protein electrophoresis.[3] It is unknown if this abnormal pattern could account for the symptoms observed.

Dr Forman also points out that a previously reported case has been discredited.[4,5] The aforementioned case was regarded as "fiction" since "many complicating factors caused a panel of experts at the AFIP [Armed Forces Institute of Pathology] to consider it not acceptable as an instance of intestinal damage due to radar."[5] However, that publication did not define specific criteria used to establish the presence or absence of microwave-related injuries.

Dr Zaret suggests that we follow up our patient to detect possible subacute and delayed effects. Approximately one year after exposure our patient has recovered his memory and is completely asymptomatic. Although microwaves are not perceived by the public as a source of harmful radiation, there are enough data available to suggest that precautions should be taken to avoid unnecessary exposure.

Mauricio Castillo, MD
Robert M. Quencer, MD
University of Miami School of Medicine/
Jackson Memorial Medical Center

1. Forman SA, Holmes CH, McManamon TV, et al: Psychological symptoms and intermittent hypertension following acute microwave exposure. *J Occup Med* 1982;24:932-934.
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Cost Containment and Quality Care

To the Editor.—In his review of *Common Diagnostic Tests: Use and Interpretation*, Dr Boisaubin[1] says, "Creating new standards for excellent, cost-effective medical care may be the greatest challenge to the practice of American medicine in the next decade. The greatest undeclared benefit of this (seminal) work lies in its potential to increase cost-effectiveness in all physician testing behavior. This manual should . . . find its way into the labcoat pocket of every thinking physician."

The first question every thinking physician should ask is whether he can lawfully consider costs in reaching his professional decisions.

I have never set foot in a law school but I learned the answer from a suit I brought against the local health commissioner and also, in effect, from a private ruling by the commissioner of the agency that licenses physicians. There is nothing whatever in New York law that permits a physician to consider costs; indeed, some court decisions have mentioned such an idea only to condemn it.

I do not suggest the law must be what it is. The legislature could permit or even require us to consider costs. That is, it could permit us to use our second-best judgment instead of our best judgment (the current standard) or it could require us to use our best judgment within the limits of third parties' willingness to pay. But the legislature has made no such changes, and physicians who act as if it has imperil themselves.

The same message has arrived from the west coast. In *Wickline v State*[2] the California Court of Appeal ruled, "While we recognize . . . that cost consciousness has become a permanent feature of the health care system, it is es-

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Radiofrequency (RF) Sickness in the Lilienfeld Study: An Effect of Modulated Microwaves?

ANA G. JOHNSON LIAKOURIS
Twin Streams Educational Center, Inc.
Carrboro, North Carolina

ABSTRACT. There is a controversy among professionals regarding whether radiofrequency radiation sickness syndrome is a medical entity. In this study, this controversy was evaluated with a methodology adapted from case studies. The author reviewed U.S. literature, which revealed that research results are sufficiently consistent to warrant further inquiry. A review of statistically significant health effects noted in the Lilienfeld Study provided evidence that the disregarded health conditions match the cluster attributed to the radiofrequency sickness syndrome, thus establishing a possible correlation between health effects and chronic exposure to low-intensity, modulated microwave radiation. The author discusses these health effects relative to (a) exposure parameters recorded at the U.S. Embassy in Moscow and (b) the Soviet 10-microwatt safety standard for the public. Given the evidence, new research—with current knowledge and technology—is proposed.

Literature Review of Human Studies

THE RADIOFREQUENCY RADIATION (RF) SICKNESS SYNDROME is a controversial medical entity in the United States. It is a systemic human response to chronic low-intensity RF exposure, identified in the 1950s by Soviet medical researchers,[1] who named it *neurotic syndrome*. Some of the symptoms are headache, ocular dysfunction, fatigue, dizziness, and sleep disorders.[2] In the United States, professionals have largely dismissed reports about this syndrome, citing it as being subjective and indicating that it results from an awareness bias; nonetheless, RF sickness syndrome has been legally recognized as "microwave radiation sickness."[3] Only in Soviet medicine[1–4] are the following clinical manifestations accepted: dermographism, tumors, hematological alterations, reproductive and cardiovascular abnormalities, depression, irritability, and memory impairment (among others). In 1978, Justesen et al.[5] recognized that Soviet research had "ecological validity," but they did not endorse the safety standard for the public (i.e., 10 microwatts [mW]). In Mitchell's 1985 review,[4] he confirmed that Soviet researchers considered the existence of neurological manifestations to be proven. In the United States, professionals simply dismissed the syndrome.

The available literature in the United States contains information in support of the RF sickness syndrome as a medical entity. Occupational studies[1,2,7–11,17] conducted between 1953 and 1991 *and* clinical cases[12–15] of acute exposure between 1957 and 1993 offer substantive evidence for the syndrome. Soviet researchers contend that the syndrome is reversible at early stages, but maintain that it is lethal over time.[16] The most valid criticism is the lack of study results that provide accurate exposure parameters linking cause and effect.

Radiofrequency Radiation Sickness in the Lilienfeld Study

The Johns Hopkins Foreign Service Health Status Study[17,18] (i.e., Lilienfeld Study) contains both medical data and properly recorded exposure parameters. To date, however, investigators have not evaluated the data, relative to RF sickness syndrome. Investigators conducted the Lilienfeld Study during the period of irradiation between 1953 and 1976 in response to the microwave irradiation of the U.S. Embassy in Moscow.

In the literature published in the United States, investigators acknowledged that elevated lymphocyte counts and protozoan intestinal diseases were the only statistically significant illnesses that occurred in Moscow Embassy personnel (versus controls). In the study investigators concluded that, at the time of analyses, there was no convincing evidence that directly implicated exposure to microwave irradiation in the causation of any adverse health effects.

It should be noted, however, that in the Lilienfeld Study, other higher and statistically significant effects, relative to controls, were not accounted for.[18] Four of the effects are clinical manifestations that the Soviets have attributed to RF sickness: (1) dermographism (i.e., psoriasis, eczema, and inflammatory and allergic skin problems); (2) neurological (i.e., diseases of the peripheral nerves and ganglia among males); (3) reproductive (i.e., problems during pregnancy, childbirth, and puerperium); and (4) tumors (benign among men, malignant among women). Other reviews of the Lilienfeld Study have contained information about additional hematological changes that occurred among the embassy personnel.[9–19] Three of the effects are mood alterations attributed to the syndrome: (1) irritability; (2) depression; and (3) loss of appetite. Two are functional deficits also attributed to the syndrome: (1) concentration difficulties and (2) refractive eye problems. The results of past and current research[20,21] have verified neurological effects resulting from microwaves that the Soviets attributed to the syndrome. All of these confirm the presence of RF sickness syndrome.

The recorded[18–22] exposure parameters were continuous-wave, broad-band, modulated microwave RF radiation. The frequency range was between 0.6 and 9.5 GHz. Exposures occurred 6–8 h/d, 5 d/wk. Each modulation (i.e., phase, amplitude, and pulse) was transmitted for only 48 h (or less) at a time. The average exposure per individual was 2–4 y. The intensity range was between 0.002 and 0.028 mW/cm^2. Intensities were 1 000 times below the safety guidelines proposed in the United States,[8] but the range met Soviet safety standards for the public—a fact that shifts attention to the properties of the exposure parameters.

The best match for the parameters[23–25] is given by the Soviet remote-sensing radar system for medical applications, described by Lin.[23] The exposures recorded at the U.S. Embassy were within the ranges of those produced by this radar system. Average power densities between 1 mW/cm^2 and 1 miliwatt/cm^2 were sufficient for the remote recording of physiological data. Given that Soviet physicians were instrumental in setting the 10-mW standard,[5] an implicit knowledge is evinced: the modulations capable of eliciting biosignals[26] from specific biological sites have key significance. Thus, we can propose both (a) that significant adverse health and behavior effects, like those found in the Lilienfeld Study, can be attributed to chronic exposure to low-intensity, appropriately modulated microwave radiation; and (b) that such a link can be verified empirically. In 1995, the U.S. Environmental Protection Agency and the National Council on Radiation Protection stated the need to formally address the health hazards of modulated RF radiation.[27]

Conclusion

The evidence from the literature review, as well as from the Lilienfeld Study, support the RF sickness syndrome as a medical entity. The evidence also calls for new research in which current biomedical engineering knowledge of biosignal processing and instrumentation are used.

* * * * * * * * *

The critical review of this study by John R. Goldsmith, M.D., Faculty of Health Sciences, Ben Gurion University of the Negev, Israel, is gratefully acknowledged. We also thank André Vander Vorst, Ph.D., head of the Microwaves Laboratory, Catholic University of Louvain, Belgium, for his encouragement to pursue this study. The legal assistance of Daniel H. Pollitt, Kenan Professor Emeritus, School of Law, University of North Carolina at Chapel Hill, is also gratefully acknowledged.

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Requests for reprints should be sent to Ana G. Johnson Liakouris, Ph.D., Twin Streams Educational Center, Inc., 243 Flemington St., Chapel Hill, NC 27514.

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Letter to the Editor

To the Editor.—The following update is offered on behalf of Jiang Xin-Min, et al., authors of the following study that appeared in the November/December 1997 (Vol. 52, No. 6 [pp 399-408]) issue of the *Archives of Environmental Health*: "Dynamics of Environmental Supplementation of Iodine: Four Years' Experience of Iodination of Irrigation Water in Hotien, Xinjiang, China."

(1) Dr. Chen Rung also contributed to this study; therefore, Dr. Chen Rung's name is hereby added to the list of those who authored this study.

(2) **Figure 1.** Figure 1, which originally appeared on page 201 of the aforementioned issue and which reflected the fate of iodine dripped in 1992 and 1993 in Long Ru and in Bakechi (1993 only), is updated to include data from 1996 in Figure 1 (p 238). If Figure 1 is examined from the top down, we find that the median urine iodine excretion of women of childbearing age in Long Ru was 55 µg/l (n = 36) in April 1996—after the last dripping in 1993; we determined the excretion before further iodine dripping was done (inadvertently) in June 1996. In Bakechi, in June of 1996, with no dripping after 1993, the median urine iodine in women of childbearing age was 105 µg/l (n = 30). Thus, in both townships urinary iodine in women increased during the third year after dripping.

In the second part of Figure 1, 1996 wheat and cabbage crops in Bakechi contained iodine concentrations that were decreased from 1995 levels, but levels remained three-fold greater than baseline levels (data not available for Long-Ru).

In the third part of Figure 1, iodine content was dramatically increased in thyroid glands of sheep (4 y of age at slaughter, n = 4 in each township) to 28 000 µg/100 g. (In comparison, the average iodine concentration in human thyroid glands in the United States is approximately 70 000 µg/100 g.) This increase may have resulted from the marked increase in iodine availability during the preceding 3 y; it may be compared with the higher, but much more modest, concentrations in urine iodine in women (above).

Finally, soil iodine concentrations increased modestly, without the spike seen after earlier drippings, in Long Ru, after further dripping (80 kg of potassium iodate) in June 1996 (Fig. 1, bottom). Soil iodine concentration was stable in Bakechi, which had no more dripping.

(3) **Figure 2.** Figure 2, which originally appeared on page 402 of the *Archives of Environmental Health* (urinary iodine concentrations in childbearing-age women in Long Ru in May 1994 [i.e., 2 y after the first dripping and 1 y after the second dripping]), is also updated, as shown on page 239 herein. The black bars indicate the proportion of the control sample that had urinary iodine concentrations within the given ranges before dripping (median = < 10 µg/l—the lower limit of detection). The open bars indicate the percentage of the test group in given ranges (median = 49 µg/l) in 1994, 1 y after the last dripping. The dotted bars indicate the distribution of urinary iodine concentrations in April 1996 (median = 55 µg/l), before any further dripping occurred.

G. Robert DeLong
Duke University Medical Center and Health System
Division of Pediatric Neurology (Box 3936)
Durham, NC 27710

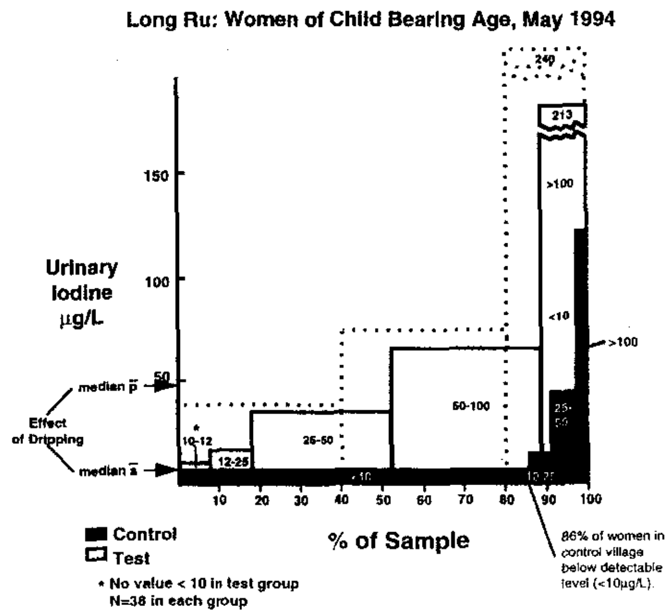

Fig. 2. Urinary iodine concentrations (mg/l) in childbearing-age women in Long Ru (updated).

1: Pathol Biol (Paris). 2000 Jul;48(6):525-8.

[Danger of cellular telephones and their relay stations]

[Article in French]

Santini R, Seigne M, Bonhomme-Faivre L.

Cellular phones and their base stations emit pulsed microwaves in the environment. Cellular phone users are exposed in the near field and, under this condition, a large part of the electromagnetic energy is absorbed by the head, leading to an increased brain temperature. The general population is exposed under far field conditions to an electromagnetic intensity depending on the distance from the base station, passive re-emitters, the number of communications maintained by the base station and their position in relation to antennae (in front of the antenna or behind). Biological effects have been reported, such as radiofrequency sickness, electroencephalographic and blood pressure changes and also cancer risks in humans and animals exposed to microwave irradiation. Some European countries (Italy, France, Belgium, etc.) have taken measures to protect their populations.

Publication Types:
- Editorial

Microwave sickness: a reappraisal

B. Hocking
Consultant in Occupational Medicine, 9 Tyrone Street, Camberwell, Victoria, Australia 3124

Microwave sickness (MWS) has been a disputed condition. The syndrome involves the nervous system and includes fatigue, headaches, dysaesthesia and various autonomic effects in radiofrequency radiation workers. This paper describes the early reports of the syndrome from Eastern Europe and notes the scepticism expressed about them in the West, before considering comprehensive recent reports by Western specialists and a possible neurological basis for the condition. It is concluded that MWS is a medical entity which should be recognized as a possible risk for radiofrequency radiation workers.

Key words: Dysaesthesia; fatigue; microwave sickness; neurological; radiofrequency.

Received 30 June 2000; accepted 23 August 2000

Introduction

The health effects of radiofrequency radiations (RFR) are controversial. (See Appendix for an introduction to the biophysics of RFR.) There is general agreement that at high levels heating effects may occur, which may be associated with burns and cataracts, for example. Effects at lower levels are subject to debate. These include effects on reproduction, cancer and ill-defined symptoms sometimes termed 'microwave sickness' (MWS) or 'radiofrequency neurasthenia'. This syndrome, which includes fatigue, headaches, palpitations, insomnia, skin symptoms, impotence and altered blood pressure, was originally described in East European radar workers but has not been well accepted in Western medicine. Recent reports by Western occupational medicine specialists have prompted a reappraisal of this position. The condition is discussed from a historical point of view, beginning with the East European literature and then recent Western reports.

East European reports

The main early report describing MWS was by Sadcikova of the Academy of Medical Sciences, USSR, in 1974 [1]. Sadcikova studied three groups, two of which worked with microwaves. The frequencies and modulations are not stated but probably included radar (pulsed) frequencies in the GHz range. One of the groups of 1000 workers was exposed to up to a 'few mW/cm^2'. The second group of 180 had exposures that 'did not exceed several hundredths of a mW/cm^2', i.e. hundreds of microwatts (μW/cm^2). These two groups were young men who had worked with radio equipment for 5–15 years. It is not stated how these study groups were defined or whether there was completeness of the survey (e.g. were sick absentees followed up). The survey appears to have been cross-sectional of existing staff rather than a cohort followed up, so those who became very ill and left may have been lost to the study. A control group of 200 of similar age and sex, and similar work without microwave exposure was included. No details are given of the completeness of this group. It appears that subjects were surveyed by questionnaire and examined. The results are presented as percentages of subjects; raw data are not presented and statistical methods are not described.

Three main syndromes were defined by Sadcikova. The first was neurological or asthenia. This included feeling 'heavy in the head', tiredness, irritability, sleepiness and partial loss of memory. For example, tiredness affected 45% of those exposed to a few mW/cm^2, 55% of those exposed to several hundredths of a mW/cm^2 and 10% of controls. Similar marked differences were found for 'heavy in the head' and irritability. Another syndrome was described for 'autonomic vascular' changes, e.g. sweating, dermographism, blood pressure changes. A third syndrome was 'cardiac', including heart pains and ECG changes.

Changes were not markedly different between mW and μW/cm^2 exposures. Those with >5 years of exposure had more symptoms, but the numbers who had <5 years of exposure are not stated (and were probably few), which makes this relationship uncertain. Sadcikova states that

Correspondence to: Bruce Hocking, Consultant in Occupational Medicine, 9 Tyrone Street, Camberwell, Victoria, Australia 3124. e-mail: bruhoc@connexus.net.au

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cessation of work involving microwave radiation frequently resulted in stabilization of the process or recovery. This imperfect study by Sadcikova loosely defined MWS to variously include: neurological or asthenic symptoms, e.g. tiredness, irritability; autonomic changes, e.g. sweating, skin changes, blood pressure changes; and cardiac changes.

Another paper in the same WHO symposium by Siekierzinski [2] describes a study of 507 people working with radar and exposed above 0.2 mW/cm^2 and 334 people working below that level. No non-exposed control group was included. They were examined for 'neurosis' and ECG and other changes. No significant differences were found between the two groups. However, it is not clear what 'neurosis' meant, and specifically if it included symptoms such as tiredness or 'heavy in the head' as in Sadcikova's survey, and so may not be strictly comparable with that work. Also, importantly, the study had no control group for absolute reference and so small differences between the study groups, which were arbitrarily dichotomized, may have been obscured. Therefore, this negative study must be interpreted cautiously.

Djordjevic *et al.* [3] studied 322 radar workers and 220 non-radar controls. Exposures to radar were for 5–10 years and generally <5 mW/cm^2. Blood tests and biochemistry were similar in the two groups. Of six subjective complaints studied, three—headache, fatigue and irritability—occurred in 28% of radar workers and 15% of controls. The difference was attributed by the authors to working conditions, e.g. noise and poor lighting, although the authors stated in the study design that they had chosen the controls matching for 'character of working regime'. Therefore, this may or may not be the correct explanation, so the study can also be interpreted as offering some support to Sadcikova's observations.

Western reports

Reports about MWS such as those cited above were treated with some scepticism by Western medical authorities [4,5]. Then, in 1982, Forman *et al.* [6] provided the first Western bloc report regarding MWS. Two USAF men who were separately, accidentally acutely irradiated with microwave radiation (radar) were followed up clinically for 12 months. Both men developed similar psychological symptoms, which included emotional lability, irritability, headaches and insomnia. Several months after the incidents, hypertension was diagnosed in both patients. No organic basis for the psychological problems could be found, nor could any secondary cause for the hypertension. The authors concluded that the two cases, with comparable subjective symptoms and hypertension following a common exposure, provided strong, circumstantial evidence of cause and effect, and noted similarities to the East European reports. Recently, Braune *et al.* [7] have reported increases in blood pressure in subjects exposed double blind to mobile phones.

In 1997, Schilling [8] provided a detailed report of effects of overexposure in three engineers working on 785 MHz television in the UK. They were exposed to fields >>20 mW/cm^2 for 1–3 min. Subsequently, they have experienced headaches, dysaesthesia, lassitude and loss of stamina for up to 3 years. They had previously been fit with no history of mental or other ill-health. This report, by an experienced occupational physician, is most pertinent to the MWS debate. The fact that the symptoms arose after an overexposure should not obscure the fact that after this they suffered long-term subjective effects, including headaches, lassitude and general malaise. This gives strong support to the view that RFR can cause the symptoms of MWS. Schilling [9] has reported further similar cases involving overexposure to FM VHF. Following two separate incidents with exposures of up to 10 and 20 mW/cm^2, two men in each incident developed persistent symptoms including effects on the central nervous system (headaches, fatigue and malaise), peripheral nerves (dysaesthesia, impaired sensation) and autonomic nervous system (diarrhoea). The symptoms have lasted >4 years in some cases.

Hocking has studied various exposures to RFR. In one accident, two men were exposed to unmodulated 4.1 GHz at between 0.31 and 4.6 mW/cm^2 for ~90 min [10]. Neither had short- or long-term symptoms, hence this was interpreted as a negative study. However, Schilling's cases, occurring after AM and FM exposure, raise the possible importance of modulations, and the absence of modulations may be a key issue in this negative report. Hocking [11] has also described cranial symptoms in a case series of 40 mobile phone users. These included dysaesthesia on the scalp, visual disturbance in a few and a feeling of 'fuzziness' in the head in a few. The reports of 'fuzziness' are similar to Sadcikova's description of 'heavy in the head'.

Bergqvist [12] has recently reviewed some of the literature regarding radiofrequency neurasthenia (i.e. MWS) and concluded that studies have not revealed any consistent evidence for an effect. However, he omitted to consider the major study by Sadcikova [1] and misinterpreted the Siekierzinski [2] study as being between exposed and 'non-exposed' groups [12], which is crucially incorrect for the reasons discussed above. He refers to the large study by Robinette *et al.* [13] of admissions to hospital of 20 000 US naval personnel who worked with radar at levels >1 mW/cm^2 compared with 20 000 who worked at levels <1 mW/cm^2, which found no excess admissions for mental disorders in the more exposed group. However, it is rare for those suffering from neurasthenia to be admitted to hospital since the condition is usually investigated and treated on an out-patient basis and so a null finding is to be expected. Also, the differences in exposure between groups were blurred as the low exposure group took recreation on deck where they were exposed up to 1 mW/cm^2, thus lessening the likelihood of finding differences. He also discusses some workplace studies which are too small to allow conclusions to be drawn. Therefore, there is good reason to disagree with Bergqvist's conclusion.

The mechanism of injury that could cause MWS has not been clear. Even with the high levels of overexposure in Schilling's cases, the cause of the persistent effect on the nervous system is not known; there were no localizing signs on examination or on brain scan such as would have been expected from heating of tissue. Modulated radiofrequency at low levels of exposure has been shown to affect calcium flux in chicken brains [14] and effects on neurotransmitters have also been shown in animal experiments [15]. Recently, Hocking and Westerman [16] have reported a subtle abnormality of nerve conduction on the scalp in a patient with persistent dysaesthesiae after low-level exposure from a mobile phone. The A and C fibres were shown to have altered current perception thresholds leading to the sensory abnormalities. Similar alterations in neural function in the central and autonomic nervous systems could provide a neurological basis for MWS.

The diagnosis of the condition is largely by exposure history, clinical data (particularly dysaesthesiae) and exclusion of other organic and psychiatric causes. At present, there are no diagnostic tests specific for RFR injury, although Nilsson *et al.* [17] found an abnormal protein in the CSF of asymptomatic radar workers. Provocation tests may be considered, but present ethical and technical problems.

Conclusion

The cases reports by Forman *et al.* and Schilling have helped better define the syndrome of MWS, which effects the central nervous system (headaches, fatigue and malaise), peripheral nerves (dysaesthesia, impaired sensation) and autonomic nervous system (diarrhoea, raised blood pressure). The symptoms have lasted for years in some cases.

The cases of Forman *et al.* and of Schilling which occurred after a brief overexposure give validity to the condition of MWS, and hence substance to Sadcikova's [1] original description of symptoms which occurred after much lower exposures. The recent description of a change in neurological function after low-level exposure from a mobile phone suggests a neural basis for the syndrome. MWS should be considered a potential health risk for RFR workers. Further work is needed to characterize the dose–response relationship and the role of modulations.

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Appendix [18]

Biophysics of RFR

RFR includes electromagnetic waves ranging from 300 kHz to 300 GHz frequencies. It is different from power line frequency (which is 50 Hz) and has different interactions with the body in that RFR couples (interacts) much better and has modulations which may have biological effects. Modulations, e.g. frequency (FM) or amplitude (AM), are small modifications to the carrier wave which allow it to carry information such as sound, or there may be pulsed modulations, e.g. radar.

Whole-body interaction

The different frequencies of RFR have widely differing wavelengths which result in different coupling (uptake) by the body. kHz waves are very long (~100 m) and have minimal uptake. Waves at 30–300 MHz are 5–1 m long, respectively, and have maximal coupling. The higher MHz and GHz waves are centimetres–millimetres in length, respectively, and exposure results in localized deposition in skin, eyes, testis, head or superficial layers of the body. Thus, energy deposition into the body is complex and varies across the RFR spectrum.

Mechanism of action

Once RFR is coupled to the body, it can interact to cause biological effects. There is general agreement that if sufficient energy is absorbed, it can cause heating by the rapidly alternating field agitating dipolar molecules, particularly water, and so cause deleterious effects (similar to warming food in a microwave oven). The present safety standards are largely based on preventing these heating effects. There is dispute as to whether lower levels of energy can cause biological effects (non-thermal, athermal mechanisms). Modulations may be important in this regard [14].

1: Pathol Biol (Paris). 2002 Jul;50(6):369-73.

Erratum in:
- Pathol Biol (Paris). 2002 Dec;50(10):621.

[Investigation on the health of people living near mobile telephone relay stations: I/Incidence according to distance and sex]

[Article in French]

Santini R, Santini P, Danze JM, Le Ruz P, Seigne M.

Institut national des sciences appliquees, laboratoire de biochimie-pharmacologie, batiment Louis Pasteur, 20, avenue Albert Einstein, 69621 Villeurbanne, France. rsantini@insa-lyon.fr

A survey study using questionnaire was conducted in 530 people (270 men, 260 women) living or not in vicinity of cellular phone base stations, on 18 Non Specific Health Symptoms. Comparisons of complaints frequencies (CHI-SQUARE test with Yates correction) in relation with distance from base station and sex, show significant ($p < 0.05$) increase as compared to people living > 300 m or not exposed to base station, till 300 m for tiredness, 200 m for headache, sleep disturbance, discomfort, etc. 100 m for irritability, depression, loss of memory, dizziness, libido decrease, etc. Women significantly more often than men ($p < 0.05$) complained of headache, nausea, loss of appetite, sleep disturbance, depression, discomfort and visual perturbations. This first study on symptoms experienced by people living in vicinity of base stations shows that, in view of radioprotection, minimal distance of people from cellular phone base stations should not be < 300 m.

1: Pathol Biol (Paris). 2003 Sep;51(7):412-5.

[Symptoms experienced by people in vicinity of base stations: II/ Incidences of age, duration of exposure, location of subjects in relation to the antennas and other electromagnetic factors]

[Article in French]

Santini R, Santini P, Danze JM, Le Ruz P, Seigne M.

Institut national des sciences appliquees, laboratoire de biochimie-pharmacologie, batiment Louis-Pasteur, 69621 cedex, Villeurbanne, France. rsantini@insa-lyon.fr

This is the 2nd part of a survey study conducted on 530 people (270 men, 260 women) living or not in vicinity of cellular phone base stations. Comparison of complaints frequencies for 16 Non Specific Health Symptoms was done with the CHI-Square test with Yates correction. Our results show significant increase ($p < 0.05$) in relation with age of subjects (elder subjects are more sensitive) and also, that the facing location is the worst position for some symptoms studied, especially for distances till 100 m from base stations. No significant difference is observed in the frequency of symptoms related to the duration of exposure (from < 1 year to > 5 years), excepted for irritability significantly increased after > 5 years. Other electromagnetic factors (electrical transformers, radio-television transmitters,...) have effects on the frequency of some symptoms reported by the subjects.

APPENDIX B

Angular Momentum of Non-Ionizing Electromagnetic Radiation

Marjorie Lundquist

May 25, 2005

Ever since John Henry Poynting published his theoretical papers during the first decade of the twentieth century, physicists have been aware that the three classical conservation principles—conservation of energy, conservation of linear momentum, and conservation of angular momentum—apply to the interaction of light and other forms of non-ionizing electromagnetic radiation with matter.

Whenever non-ionizing electromagnetic radiation interacts with matter, there is ***always*** an exchange of both energy and linear momentum. However, there can be an exchange of angular momentum only if the field possesses ***non-zero*** angular momentum, because otherwise the field has no angular momentum to transfer to the matter. This means that, with respect to the angular momentum of an electromagnetic field, the safest field is one having ***zero*** angular momentum.

A beam of circularly polarized light (or radiofrequency radiation) possess non-zero angular momentum, and therefore poses a potential health hazard if it irradiates a living creature. This constitutes non-zero *spin angular momentum*. A beam of light may also possess *orbital angular momentum*. Some very exciting research in physics is currently being done using laser light that possesses non-zero orbital angular momentum.

The paper I presented at the March 2005 meeting of the American Physical Society identifies the presence of non-zero orbital angular momentum in the near field of a transmitter emitting plane-polarized radiofrequency radiation. This constitutes a near-field hazard to health that is not controlled by existing health protection standards.

Reference

Miles Padgett, Johannes Courtial & Les Allen. *Light's orbital angular momentum.*
Physics Today 57(5):35-40 (May 2004).

Light's Orbital Angular Momentum

The realization that light beams can have quantized orbital angular momentum in addition to spin angular momentum has led, in recent years, to novel experiments in quantum mechanics and new methods for manipulating microparticles.

Miles Padgett, Johannes Courtial, and Les Allen

Like all wave phenomena, light has mechanical properties. Johannes Kepler suggested that comet tails always point away from the Sun because light carries linear momentum. In 1905, John Poynting developed the theory of electromagnetic radiation pressure and momentum density and, in 1921, Albert Einstein showed that Planck's blackbody law and the motion of molecules in a radiation field could be explained if the linear momentum of a photon is $\hbar\mathbf{k}$. (The wave number $k = 2\pi/\lambda$ and $\hbar = h/2\pi$, where λ is the wavelength and h is Planck's constant.) In modern times, light's linear momentum has been directly exploited for trapping and cooling atoms and molecules.

It was also Poynting who, in 1909, realized that polarized light has angular momentum—spin angular momentum, associated with circular polarization. For a single photon, it has a value of $\pm\hbar$. The idea of light's orbital angular moment came only much later: In 1992, a group at Leiden University in the Netherlands that included one of us (Allen) recognized that light beams with an azimuthal phase dependence of $\exp(-i\ell\phi)$ carries an angular momentum independent of the polarization state.[1] The angle ϕ is the azimuthal coordinate in the beam's cross section, and ℓ can take any integer value, positive or negative. This *orbital* angular momentum, they predicted, would have a value of $L = \ell\hbar$ per photon. Just as with circularly polarized light, the sign of the orbital angular moment indicates its handedness with respect to the beam direction.

For any given ℓ, the beam has ℓ intertwined helical phase fronts, as illustrated in figure 1. A feature of helically phased beams is that the phase singularity on the beam axis dictates zero intensity on the axis. Therefore the cross-sectional intensity pattern of all such beams has an annular character that persists no matter how tightly the beam is focused. The on-axis singularity is a specific instance of phase dislocation, the general literature for which is recent, extensive, and beyond the scope of this article.[2]

The concept of optical orbital angular momentum of light is not altogether new. It is well known that multipolar transitions can produce radiation that carries orbital angular momentum. But such processes are rare and relate, in the visible, to a few "forbidden" atomic and molecular transitions. What's new and exciting is that it is now possible to produce, rather easily, laboratory light beams with quantized orbital angular momentum. These beams can be used to investigate all the analogues of polarized light. For example, one can look for a photon analogue of the spin–orbit coupling of electrons and, quite generally, to search for new optical interactions.

Miles Padgett *and* **Johannes Courtial** *are physicists at Glasgow University in Scotland.* **Les Allen** *holds visiting appointments at the Universities of Glasgow, Strathclyde, and Sussex.*

Optical angular momentum

To a considerable extent, one can understand light's momentum properties without reference to photons. A careful analytic treatment of the electromagnetic field gives the total angular momentum of any light field in terms of a sum of spin and orbital contributions.[1] In free space, the Poynting vector, which gives the direction and magnitude of the momentum flow, is simply the vector product of the electric and magnetic field intensities. For helical phase fronts, the Poynting vector has an azimuthal component, as shown in figure 1. That component produces an orbital angular momentum parallel to the beam axis. Because the momentum circulates about the beam axis, such beams are said to contain an optical vortex.

The most common form of helically phased beam is the so-called Laguerre–Gaussian (LG) laser mode. In general, lasers emit a beam that gradually expands as it propagates. The magnitude and phase of the electric field at different positions in the cross section are described by a mode function. For most laser beams without helical phasing, that function is the product of a Hermite polynomial and a Gaussian. Hermite–Gaussian (HG) modes have several intensity maxima, depending on the order of the polynomials, arrayed in a rectilinear pattern and separated by intensity zeros.

The cylindrical LG modes have an explicit $\exp(-i\ell\phi)$ phase factor. That makes them the natural choice for the description of beams carrying orbital angular momentum. Although LG modes have been produced directly in laser systems,[3] they are more easily produced by the conversion of HG beams.

Generating the beams

Spin angular momentum depends only on the polarization of the beam, not on its phase. Therefore both HG and LG beams can possess spin angular momentum. Beams carrying spin angular momentum are readily produced by using a quarter-wave plate to convert linearly into circularly polarized light. The Leiden group introduced an analogous trick with cylindrical lenses to transform an HG beam with no angular momentum into a LG beam that carries orbital angular momentum (see figure 2).[4]

Although this conversion process is highly efficient, each LG mode does require a particular initial HG mode. That requirement limits the range of LG modes one can produce. Consequently, the most common method for cre-

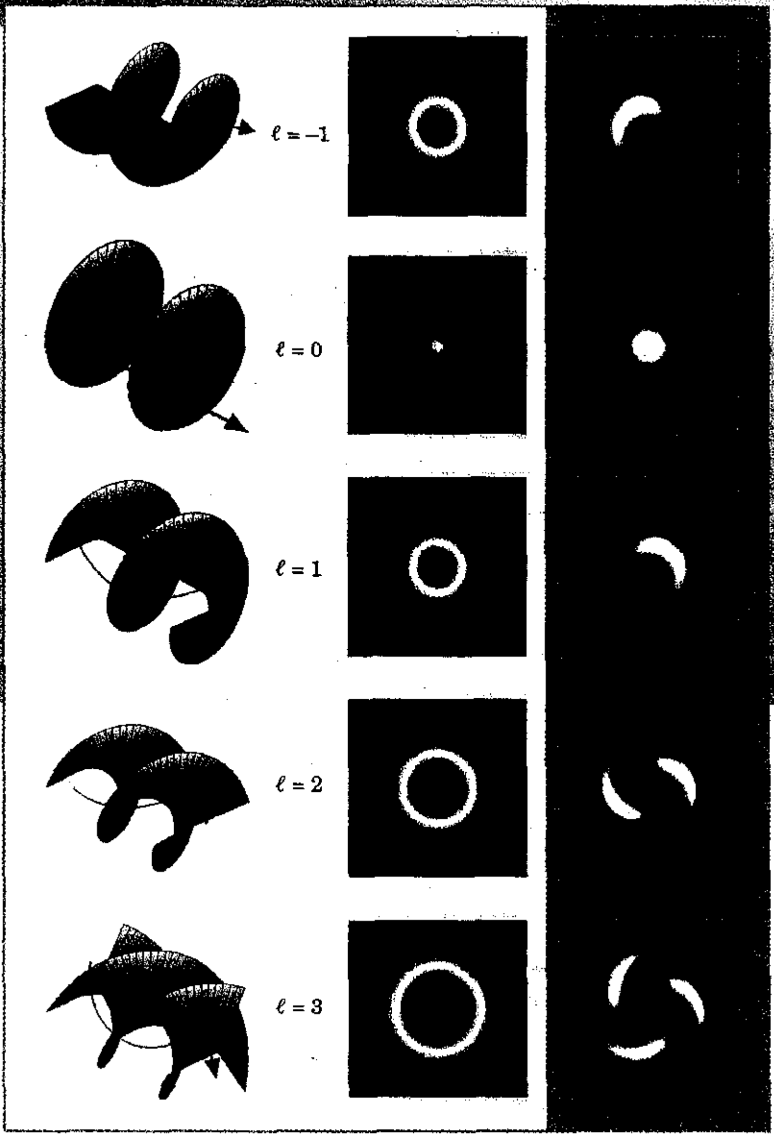


Figure 1. Orbital angular momentum of a light beam, unlike spin angular momentum, is independent of the beam's polarization. It arises from helical phase fronts (left column), at which the Poynting vector (green arrows) is no longer parallel to the beam axis. At any fixed radius within the beam, the Poynting vector follows a spiral trajectory around the axis. Rows are labeled by ℓ, the orbital angular-momentum quantum number. $L = \ell\hbar$ is the beam's orbital angular momentum per photon. For each ℓ, the left column is a schematic snapshot of the beam's instantaneous phase. An instant later, the phase advance is indistinguishable from a small rotation of the beam. By themselves, beams with helical wavefronts have simple annular intensity profiles (center column). But when such a beam is made to interfere with a plane wave [illegible] spiral intensity pattern (right column). The number of spiral arms equals the [illegible] of the helical beam.

ating helical beams has been the use of numerically computed holograms. Such holograms can generate beams with any desired value of orbital angular momentum from the same initial beam (see figure 3). The requisite hologram can be formed by recording, onto photographic film, the interference pattern between a plane wave and the beam one seeks to produce. Illuminating the resulting hologram with another plane wave produces a first-order diffracted beam with the intensity and phase pattern of the desired beam.

The holographic approach can take advantage of the high-quality spatial light modulators (SLMs) that have recently become available. These pixelated liquid-crystal devices take the place of the photographic film. Furthermore, numerically calculated holographic patterns can be displayed on an SLM. These devices produce reconfigurable, computer-controlled holograms that allow a simple laser beam to be converted into an exotic beam with almost any desired phase and amplitude structure. And the beam pattern can be changed many times per second to meet experimental requirements. Figure 3 shows how a comparatively simple "forked" holographic pattern can transform the plane-wave output of a conventional laser into a pair of LG beams carrying orbital angular momentum.[5] In recent years, SLMs have been used in applications as diverse as adaptive optics, real-time holography, and optical tweezing.

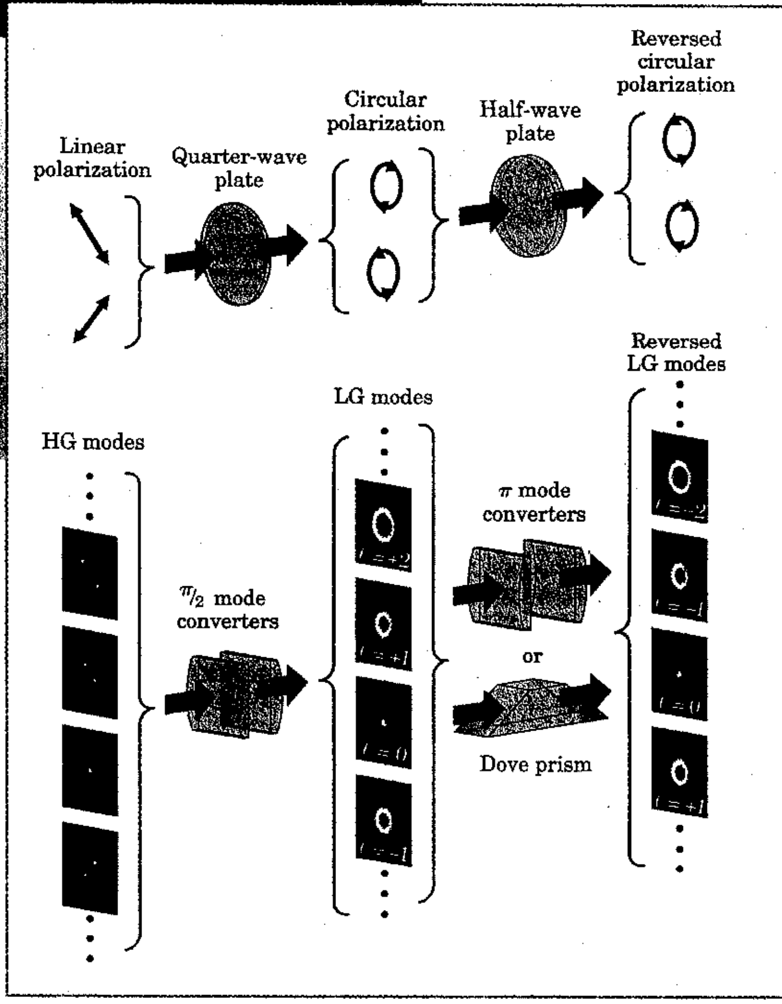
Unlike spin angular momentum, which has only two independent states corresponding to left- and right-handed circular polarization, orbital angular momentum has an unlimited number of possible states, corresponding to all integer values of ℓ. Although the link between spin angular momentum and circular polarization is clear, the link between orbital angular momentum and other ways of describing the beam is less obvious. It's tempting, for example, to directly associate the orbital component to the ℓ-value of an optical vortex; but that's wrong. Because the center of the vortex is a position of zero optical intensity, it carries neither linear nor angular momentum. Instead, the angular momentum is associated with regions of high intensity, which for an LG mode is a bright annular ring.

That association is well illustrated by a recent experiment by Lluis Torner and coworkers at the University of Catalonia in Barcelona, Spain.[6] They showed that, after the beam passes through the focus of a cylindrical lens, the azimuthal component of the linear momentum near the vortex center is reversed, but the total orbital angular momentum of the beam remains unchanged. The reversal of the vortex is simply image inversion in geometrical optics; it has no implications for orbital angular momentum.

Orbital angular momentum arises whenever a beam's phase fronts are not perpendicular to the propagation direction. In the approximation of geometric optics, one would say that the light rays that make up the beam are skewed with respect to its axis. Simplistic as it is, this skewed-ray model predicts the correct result in most experimental situations.

Measuring the angular momentum of a light beam is not easy. The first demonstration of the transfer of spin angular momentum from a light beam was carried out in 1936 by Richard Beth at Princeton University.[7] The experiment was extremely demanding. A suspended quarter-wave plate took angular momentum from a circularly polarized beam. The plate's macroscopic size and corresponding high moment of inertia, however, meant

Figure 2. A pair of cylindrical lenses can serve as a converter that transforms a Hermite–Gaussian (HG) mode into a Laguerre–Gaussian (LG) mode carrying orbital angular momentum, much as a quarter-wave plate converts linearly polarized light to circular polarization. Because the same lens pair works for any HG mode, it can produce a wide range of LG modes. Increasing the separation between the cylindrical lenses can reverse the handedness of the LG mode, just as a half-wave plate reverses circular polarization [illegible]



that its resultant rotation was tiny.

The analogous experiment for transferring orbital angular momentum to a suspended cylindrical lens has proved too difficult. Instead, a number of groups have examined angular-momentum transfer to microscopic particles held by optical tweezers.[8] Optical tweezers rely on the strong intensity gradient at the tight focus of a laser beam. At such a focus, any small, lightweight dielectric particle experiences a gradient force sufficient to attract it to the axis. So the particle is held in place without mechanical suspension.

In 1995, Halina Rubinsztein-Dunlop and coworkers at the University of Queensland in Brisbane, Australia, used an unpolarized, helically phased laser beam to impart orbital angular momentum to a small ceramic particle held by optical tweezers.[9] In 1998, the Brisbane group repeated the experiment,[10] this time imparting spin angular momentum from a polarized beam to a birefringent particle—a microscopic encore to Beth's 1936 experiment.

The previous year, two of us (Padgett and Allen) performed an experiment with Neil Simpson that demonstrated the use of a circularly polarized *and* helically phased beam as an optical wrench (in Britain we call it an optical spanner).[11] We showed, for $\ell = 1$, that when the spin and orbital angular-momentum components of the beam had the same sense, they combined to induce a rapid rotation of a small transparent particle. But when they were of opposite sense, summing to zero angular momentum, the particle did not rotate. This later experiment demonstrated that the orbital angular momentum associated with $\ell = 1$ is mechanically equivalent to the angular momentum $\hbar$ associated with photon spin.

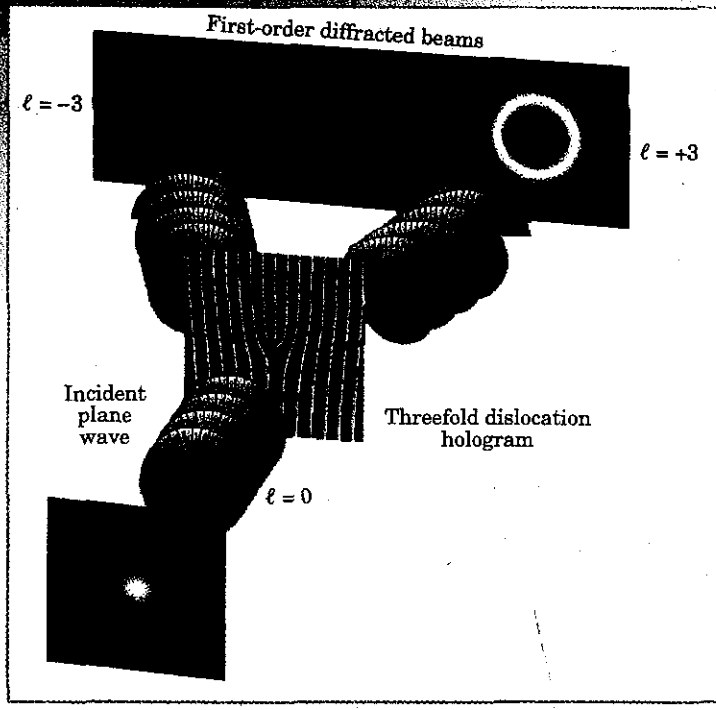
Although spin and orbital angular momentum are equivalent in many ways, they have, in general, different interaction properties. Because the orbital angular momentum of a light beam arises from the inclination of its phase fronts, its interactions with particles away from the axis are most easily understood in terms of the azimuthal component of the beam's linear momentum.

At the microscopic level, such interactions have been observed with polarized helical beams acting also as optical tweezers (see figure 4). In several experiments, a small transparent particle was confined away from the axis in the beam's annular ring of light.[12] The particle's tangential recoil due to the helical phase fronts caused it to orbit around the beam axis. At the same time, the beam's spin angular momentum caused the particle to rotate on its own axis.

At the level of individual atoms, things are somewhat different. Spin angular momentum per photon is a constant at every position within the beam. For example, a Zeeman transition can be excited by circularly polarized light of the appropriate frequency anywhere an atom finds itself within the beam's cross section. By contrast, orbital angular momentum is not transferred in the same way to atoms positioned at different radial distance from the beam axis. It is the Poynting vector's tangential component that makes the atom orbit the beam axis.

The detailed behavior of the atom is modified by frequency shifts, relaxation times, and the atom's degree of excitation. In 1994, such effects were analytically examined for atoms in LG beams by Allen, Mohamed Babiker, and coworkers.[11] Their calculation showed that, in addition to the torque around the axis, the atom experiences a shift in transition frequency. Both effects are proportional to the beam's orbital angular momentum.

Spin–orbit coupling of electrons determines much of the atom's energy-level structure. In an attempt to see if such a coupling can also exist for photons, Allen and company have shown that a light beam exerts a dissipative azimuthal force on atoms proportional to the product of the beam's spin and orbital angular momentum.[13] That force is very small—of the same order as terms invariably neglected in atom-trapping theory. But the prediction that this tiny force should be reversed when the beam's spin changes handedness was a novel one.



[illegible] per photon. The appropriate hologram can be calculated, or it can be generated from the interference pattern between the desired beam form and a plane wave. The resulting holographic pattern resembles a diffraction grating, but it has an ℓ-pronged dislocation at the beam axis. (The one shown here has three prongs.) When the hologram is illuminated with a plane wave, the first-order diffracted beams have the desired helical phase fronts.

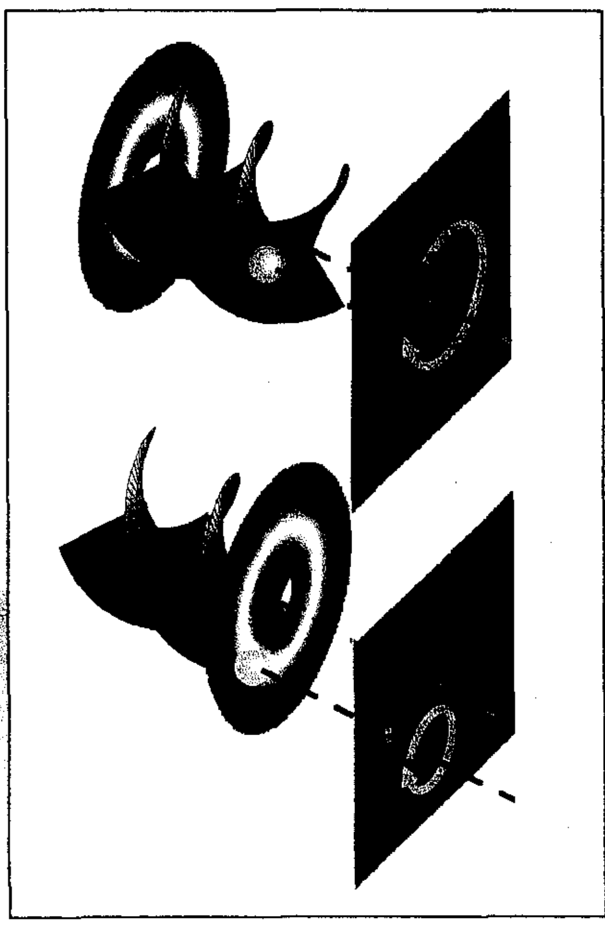
Rotational frequency shifts

In 1979, Bruce Garetz and Stephen Arnold at the Polytechnic Institute in New York observed that a circularly polarized light beam is frequency shifted if it is steadily rotated about its own axis.[14] Classically, this shift is simply what one would observe if a clock were laid face up at the center of a rotating turntable. Looking down on the clock's face, one seems to see the second hand sweeping at the wrong angular speed—the sum of the clockwork motion and the turntable's rotation.

Circularly polarized light behaves in just the same way. The rotation of the beam on its axis slightly speeds up or slows down the much faster optical rotation of the electric field vector. The mechanical rotation can be achieved with a rotating half-wave plate. This rotational frequency shift is, in some sense, an angular Doppler shift. But it is not the same as the Doppler shift associated with rotating bodies viewed from the side, which is simply a manifestation of the usual translational Doppler effect in which the rotation of an object produces a linear-velocity component along the line of sight. In fact, the angular Doppler shift is maximal when the line of sight is the rotation axis—precisely the direction in which the linear Doppler shift vanishes.

In 1998, our Glasgow group managed to observe the rotational frequency shift with a linearly polarized millimeter-wave beam that carried orbital angular momentum; millimeter-wave beams are more forgiving than shorter wavelengths of inevitable misalignments in such experiments.[11] The key to understanding the frequency shift in a helical beam is to recognize that the time evolution of a helical phase front is indistinguishable from rotation about the beam axis. So, a single rotation of the beam advances or retards its phase by ℓ cycles.

In a follow-up experiment later that year, with a beam that had both circular polarization and a helical phase front, we showed that spin and orbital angular momentum combine to give a rotational frequency shift proportional to the *total* angular momentum. That result is a generalization of the frequency shift predicted by Iwo and Zofia Bialynicki-Birula at Warsaw University in 1997 for the transition frequency of a rotating atom.[15]



Interaction with nonlinear crystals

The high power density achievable with focused laser beams has made nonlinear optics a common phenomenon in the optics laboratory. In much the same way that large input voltages cause audio amplifiers to distort, yielding

Figure 4. Transferring angular momentum from light to matter can make the matter rotate. When a circularly polarized laser beam with helical phase fronts traps a micron-sized dielectric particle (yellow ball) in an annular ring of light around the beam axis, one can observe the transfer of both orbital and spin angular momentum.[12] The trapping is a form of optical tweezing accomplished, without mechanical constraints, by the ring's intensity gradient. The orbital angular momentum transferred to the particle makes it orbit around the beam axis (top). The spin angular momentum, on the other hand, sets the particle spinning on its own axis (bottom).

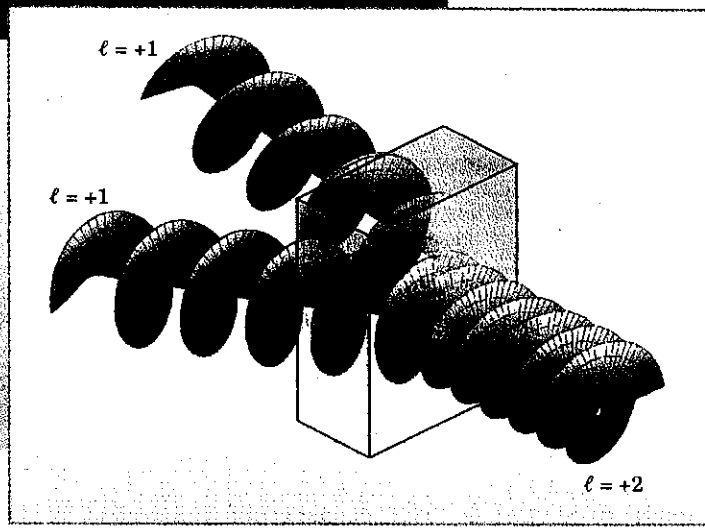


Figure 5. Second-harmonic generation with helical phase-front light beams in a nonlinear crystal conserves orbital angular momentum as well as linear momentum and energy within the light field. The two input beams are from the same source, and the output frequency is double that of the input. The process also doubles $\ell\hbar$, the orbital angular momentum per photon. Nonlinear effects in a dielectric crystal can also produce a reverse three-photon interaction that results in frequency down-conversion. A single high-energy photon becomes two photons of lower energy. That phenomenon also conserves energy, linear momentum, and orbital angular momentum within the light field.

output that contains extraneous frequencies, intense light beams distort the dielectric response of many optical crystals. This distortion, or nonlinearity, causes the light emitted by the crystal to include frequencies that were not in the optical input.

The most efficient nonlinear processes involve interaction among three waves. One either combines two incident waves to form a third, in a process known as frequency up-conversion, or one performs frequency down-conversion by splitting a single incoming wave into two. In both cases, conservation of energy at the photon level dictates that the largest of the three frequencies is the sum of the two lesser frequencies.

Conservation of momentum also plays a role. When the interacting beams are plane waves, all the Poynting vectors are collinear, and momentum conservation dictates a relationship among the three refractive indices. The requisite balancing of refractive indices is called phase matching. Remember that the Poynting vector in helically phased beams describes a spiral trajectory around the beam axis. One might think that this spiraling modifies the phase-matching conditions; but that's not the case.

Consider, for example, second-harmonic generation in which a single beam, split in two, constitutes both inputs, and the output beam is doubled in frequency. The orbital angular momentum is also doubled (see figure 5). In the photon picture, this means that two photons combine to form one photon of twice the energy, twice the linear momentum, and twice the orbital angular momentum. Contrast this conservation of orbital angular momentum within the light fields against what happens to the photons' spin. There has to be a transfer of spin angular momentum to the frequency-doubling crystal, because a single photon cannot have a spin angular momentum of $2\hbar$.

For down-conversion, energy conservation allows the initial beam to be split into two input beams with any combination of frequencies, so long as their sum equals the frequency of the initial beam. The phase-matching condition is what controls that frequency-splitting ratio. But there is nothing like the phase-matching restriction to constrain the division of the initial orbital angular momentum between the two input beams. In principle, any combination of orbital angular momenta that conserves the initial beam's orbital angular momentum is allowed. In fact, each of the split beams is in a mixture of orbital angular momentum states with a well-defined mean value. But as we shall see, the peculiarly quantum mechanical relationship between the beams can only be observed at the single-photon level.

Any number of fields can interact nonlinearly within the constraints of energy and momentum conservation. But efficiency imposes practical limits. Take, for example, four-wave mixing in which three light waves combine to produce a fourth. One such process is phase conjugation, which occurs when a nonlinear material is optically excited by two pump beams so that an additional signal beam creates a beam traveling in the opposite direction with opposite phase. It's a kind of mirror.

In a recent phase-conjugation experiment at Pernambuco Federal University in Recife, Brazil, Sergio Barreiro and Jose Wellington Tabosa used cold cesium atoms as the nonlinear material.[16] They reported that if the signal beam carries orbital angular momentum, its phase information and angular momentum is transferred first to the atoms and then, after a deexcitation time, to the "reflected" beam. Such a mechanism might one day be exploited for memory storage in multidimensional information processing.

Quantum effects

The first truly quantum-mechanical experiment using light beams with orbital angular momentum was reported in 2001 by Anton Zeilinger's group at the University of Vienna.[17] In a down-conversion experiment, the group demonstrated that the conservation of orbital angular momentum applied individually to each pair of emitted photons. This demonstration extended to orbital angular momentum the analogous tests of quantum mechanics carried out by Alain Aspect's group in the early 1980s. They had shown that the spin angular momentum of down-converted photon pairs was an entangled quantum state. The spin of a photon is defined by two states. But, as we've seen, the number of possible orbital angular-momentum states is unlimited. That difference presents the prospect of a deeper examination of quantum entanglement between photon states than has previously been possible.

The degree of a beam's polarization is readily measured with a polarizer. But orbital angular momentum, because of the arbitrarily large number of quantum states, is more difficult to quantify. One can check for a specific value of ℓ by means of the same holograms one uses to create helical phase fronts. But that method doesn't permit the ℓ of individual photons to be measured unambiguously.

Last year, however, our group devised a method for using interferometers to sort single photons into their different orbital angular-momentum states.[11] Our interferometer had a beam rotator in one arm. That introduced an ℓ-dependent phase shift that allowed the photons to be sorted into states of odd and even ℓ. Subsequent interferometer stages then permitted further sorting into specific

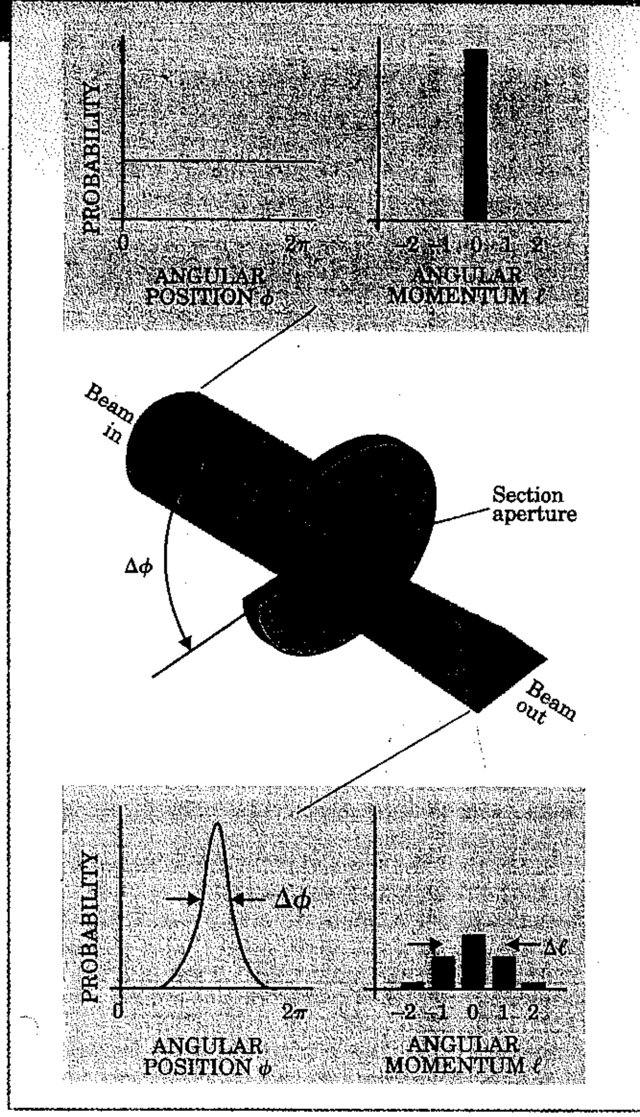


Figure 6. Heisenberg's uncertainty principle is manifested in a recent experiment at Glasgow University with a light beam that initially carries no orbital angular momentum. The range $\Delta\phi$ of azimuthal angular positions for a photon in a cross section of the beam is defined by a sector aperture. Upstream of the aperture, the beam is in an $\ell = 0$ eigenstate of orbital angular momentum (upper panel). But the uncertainty principle dictates that the restriction in ϕ introduce a spread (lower panel) in the orbital angular momentum $L = \ell\hbar$ per photon. For narrow apertures, the relationship is $\Delta\phi\Delta L \geq \hbar/2$.

orbital angular-momentum states.

An essential aspect of the quantum world is the fundamental limit that Heisenberg's uncertainty principle sets on the accuracy with which one can simultaneously know the values of a pair of conjugate variables. Angular position and orbital angular momentum are such a pair. In work not yet published, Steve Barnett and our group have recently demonstrated that this aspect of the Heisenberg principle can actually introduce orbital angular momentum—albeit with an expectation value of zero—into a light beam that starts out with none (see figure 6).

The experiment defines the angular position of a photon in the beam's cross section by making it pass through a V-shaped sector aperture whose apex is coincident with the beam axis. We have shown that, when a beam in an eigenstate of orbital angular momentum $L = \ell\hbar$ per photon passes through such an aperture, it acquires a distribution of orbital angular-momentum states. For narrow apertures, we showed that the product of aperture width, $\Delta\phi$, and angular momentum spread, ΔL, is bounded by $\hbar/2$, as quantum mechanics tells us it must be.

The exploration and exploitation of light with orbital angular momentum are still in early days. There's much to be learned about the interaction of such light with atoms. Exciting applications with rotating optical micromachines are in prospect. For quantum communication and information processing, the expansion of the Hilbert space of angular-momentum states offers opportunities for new approaches to encryption and data storage.

Martin Harwit has proposed that the orbital angular momentum of light from celestial sources might provide a new window on the cosmos.[18] For example, the observation of orbital angular momentum in light scattered by black holes could be very instructive. And we could search for signals from extraterrestrials who might be availing themselves of the high information density made possible by orbital angular momentum. At the birth of modern astronomy, Kepler studied the role of light's linear momentum. Perhaps astronomers will soon find something equally valuable in its orbital angular momentum.

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APPENDIX C

Abstract

of a paper presented orally

on March 24, 2005,

at a meeting of the American Physical Society

in Los Angeles, California, USA

10:48

U21 15 Today's "safe" radiofrequency (RF) exposure limits DON'T protect human health near transmitters! MARJORIE LUNDQUIST,* *The Bioelectromagnetic Hygiene Institute* Maxwell's theory implies that electromagnetic (EM) radiation carries both energy and momentum. "The momentum may have both linear and angular contributions; angular momentum [AM] has a spin part associated with polarization and an orbital part associated with spatial distribution. Any interaction between radiation and matter is inevitably accompanied by an exchange of momentum. This often has mechanical consequences ..."[2] Voluntary consensus standards [ANSI C95; NCRP; INCIRP] protect human health from most *thermal* [energy transfer] effects, but no standards yet exist to protect health against *athermal* [momentum transfer] effects, though laboratory transfer of spin AM was reported by 1935[3] and of orbital AM by 1992[2] for an optical vortex [tip of Poynting vector (PV) traces a helix about the beam axis]. In the *far field* of a dipole RF transmitter, radiation is linearly polarized (*minimal* spin AM) and locally approximated by a plane wave (*zero* orbital AM), but in the *near field* the orbital AM is *non-zero* [tip of PV traces an ellipse[4] in air] implying an *athermal hazard* [*e.g.*, brain tumors in cellular phone users] against which *no standard now in use anywhere in the world* protects! [2] L. Allen *et al.* Phys. Rev. A **45**:8185-9(1992). [3] R.A. Beth, Phys. Rev. **48**:471(1935); **50**:115-25 (1936). [4] F. Landstorfer, Archiv für Elektronik und Übertragungstechnik **26**:189-96(1972) [in German].

*P.O. Box 11831, Milwaukee WI 53211-0831 USA

SOURCE:

Bulletin of the American Physical Society, vol. 50, no. 1, part II, page 1178.

Today's "safe" radiofrequency (RF) exposure limits DON'T protect human health near transmitters!

Marjorie Lundquist

The Bioelectromagnetic Hygiene Institute

Milwaukee, WI 53211-0831

Presented at the American Physical Society meeting,
in Los Angeles, California, on March 24, 2005

Non-ionizing electromagnetic radiation interacts with matter, simultaneously, in 3 different ways:

- electromagnetic energy is transferred to matter; &
- electromagnetic linear momentum is transferred to matter; &
- electromagnetic angular momentum is transferred to matter.

These possibilities have been known since 1909, when John H. Poynting, student of James Clerk Maxwell, published the last of several theoretical papers.

J. H. Poynting. On the transfer of energy in the electromagnetic field. Philosophical Transactions of the Royal Society of London A 175:343-361(1884).

J. H. Poynting. On the tangential stress due to light incident obliquely on an absorbing surface. The London, Edinburgh, and Dublin Philosophical Magazine, Series 6, vol. 4, no. 49, pp. 169-171 (January 1905).

J. H. Poynting. On radiation pressure. The London, Edinburgh, and Dublin Philosophical Magazine, Series 6, vol. 4, no. 52, pp. 393-406 (April 1905).

J. H. Poynting. The wave motion of a revolving shaft, and a suggestion as to the angular momentum in a beam of circularly polarized light. Proceedings of the Royal Society of London A 82(557):560-567 (July 31, 1909).

In the Western Hemisphere, the first voluntary consensus standard intended to protect human health from exposure to non-ionizing electromagnetic radiation was designed to protect against the temperature rise that results from too rapid an absorption of electromagnetic energy.

This thermal hazard was the only hazard to health that everyone accepted the existence of in the middle of the twentieth century.

This standard, ANSI C95 (1966), served as the prototype for all others developed by people and groups who were dissatisfied by ANSI C95. In its original (1966) form, ANSI C95 applied only to a *plane electromagnetic wave*, and it was restricted to *thermal effects*.

For a plane wave, the exposure metric for thermal effects—that is, for the absorption by matter of electromagnetic energy—is the radiation power density.

A derivation of this can be found in Chapter 4 of the book titled

WIRELESS PHONES AND HEALTH II: STATE OF THE SCIENCE

George Carlo, ed., published in 2000 by Kluwer Academic Publishers.

ANSI C95 established a "safe upper limit" to the radiation power density of 10 milliwatts per square centimeter: 10 mW/cm^2.

The IEEE, the professional society of electrical engineers, is the sponsor of ANSI C95, and therefore is responsible for revising it as needed. There have been major revisions to ANSI C95 since 1966, when it was first issued.

As early as 1955, the U.S. Department of Defense had adopted the value of 10 mW/cm^2 to protect the health of servicemen. In 1966, when ANSI C95 was first issued, this value was extended to the general population as a "safe upper limit" to microwave and radio-frequency radiation exposure.

But no action was ever taken to address the *other two ways* that non-ionizing electromagnetic fields can interact with matter: by transferring linear or angular electromagnetic momentum from the field to matter! ANSI C95 was based *only* on *thermal* health effects that result from the absorption of electromagnetic energy.

An attempt was made to incorporate animal behavioral effects in ANSI C95, but this was done only in the context of thermal effects (which was foolish). No effective action was ever taken to address the *nonthermal* effects of *momentum transfer* to matter.

For a spherical coördinate system with origin at the center of the transmitting antenna, the instantaneous volume density of torque $\boldsymbol{\tau}$ produced by the electromagnetic field is given by

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{f}$$

where $\mathbf{f}$ is the volume density of force exerted by external fields $\mathbf{E}$ and $\mathbf{B}$ on the charges and currents in the infinitesimal volume under consideration.

The equation for $\mathbf{f}$ comes from the equation for the Lorentz force $\mathbf{F}$ which, for a particle with charge q moving at velocity $\mathbf{v}$ under the influence of an external field $\mathbf{E}$ and magnetic induction field $\mathbf{B}$, is:

$$\mathbf{F} = q\,(\mathbf{E} + \mathbf{v} \times \mathbf{B}) = q\,\mathbf{E} + \mathbf{J} \times \mathbf{B}$$

(where $\mathbf{J} = q\,\mathbf{v}$). This becomes a volume density equation when the charge q is replaced by the volume density of charge ρ:

$$\mathbf{f} = \rho\,\mathbf{E} + \mathbf{j} \times \mathbf{B}$$

where $\mathbf{f}$ is the volume density of force and $\mathbf{j}$ is the volume density of current.

It can be shown that, in a linear isotropic homogeneous medium (which empty space is, and air is assumed to be), the equation for $\mathbf{f}$ becomes:

$$\mathbf{f} = \partial \mathbf{g}/\partial t - \nabla \cdot \mathsf{T}$$

where (in air) $\mathbf{g} = (1/c^2)\,\mathbf{S} = \mathbf{D} \times \mathbf{B}$ ($\mathbf{g}$ is the linear momentum density of the electromagnetic field) and T is the Maxwell stress tensor:

$$\mathsf{T} = \mathbf{DE} + \mathbf{BH} - u\,\mathsf{I}.$$

A monopole antenna mounted on a conducting plane is equivalent to a center-fed dipole antenna because the conducting plane produces an image of the real monopole antenna on its other side, like a mirror; but the image carries charge of the opposite sign.

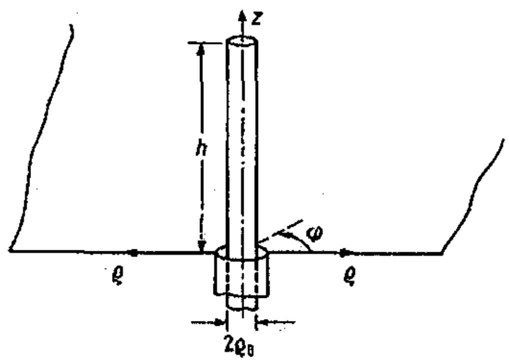
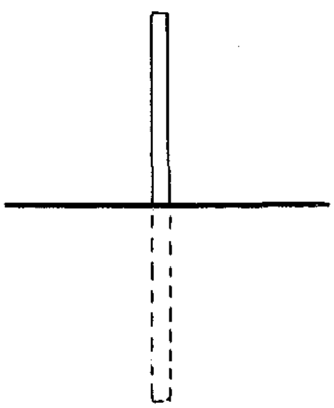
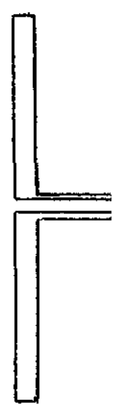


Figure 1.

Friedrich Landstorfer. Energietransport im Nahfeld von Stab-antennen [Energy flow in the near field of rod antennas]. Archiv für Elektronik und Übertragungstechnik 26(4):189-196 (April 1972). [in German]   Bild 1 [Figure 1]



monopole antenna with conducting plane



equivalent dipole antenna without conducting plane

In his 1972 paper, Landstorfer investigated the behavior of the instantaneous Poynting vector near a rod antenna. He treated a monopole antenna over a ground plane, shown in Figure 1 from his published paper. This is equivalent to a dipole antenna, as illustrated by the cross-section diagrams I have drawn beneath Landstorfer's Figure 1. (The length of the monopole antenna, *h*, is half the length L of the dipole antenna.)

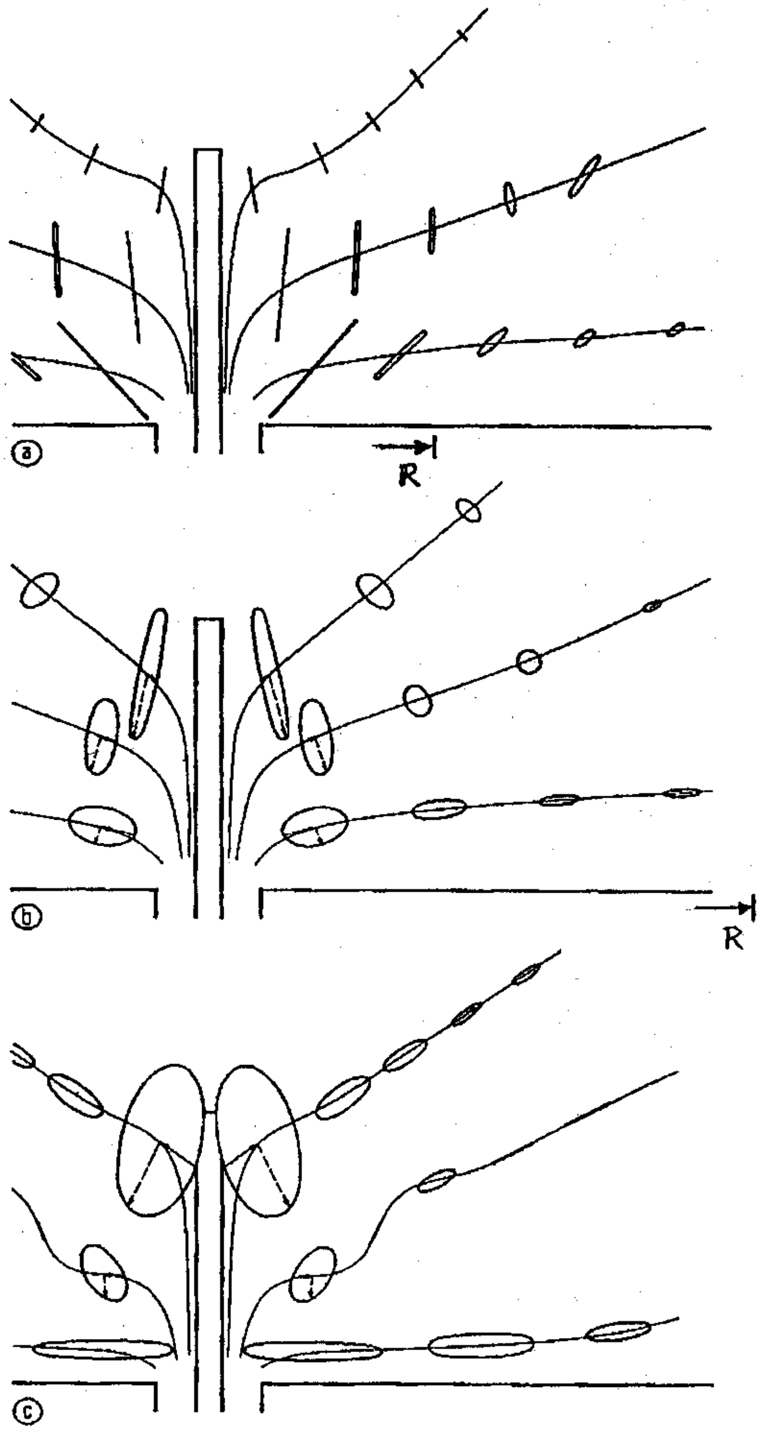
Electrical engineers are taught to compute time-averaged values of the Poynting vector, as this information is normally adequate for their needs. So electrical engineers typically remain ignorant of the instantaneous behavior of the Poynting vector. Landstorfer seems to have been the first person to publish a paper on the instantaneous Poynting vector.

Landstorfer separated the expression for the instantaneous Poynting vector into the vector sum of a time-dependent vector and a time-independent vector. He found that the time-dependent vector rotates with time so that its tip traces out an ellipse. In Figure 11 of his published paper he has drawn some of the ellipses so that each is centered at the point in space to which its Poynting vector corresponds. This makes it easy to see how the time-dependent portion of the Poynting vector varies with its location in space. (Because the antenna is a cylindrical rod, this spatial variation possesses cylindrical symmetry.)

$$L = 2\,h$$

L = length of dipole antenna; h = length of monopole antenna

$$R_{near/far} = 2\,L^2/\lambda_0 = 2\,(L/\lambda_0)\,L = 4\,(L/\lambda_0)\,h$$



$L = \lambda_0/5;\ \ L/\lambda_0 = 0.2$
$h = \lambda_0/10$
$R_{near/far} = 0.8\,h$
ellipses mostly closed:
field A.M. nearly zero

halfwave dipole antenna
$L = \lambda_0/2;\ \ L/\lambda_0 = 0.5$
$h = \lambda_0/4$
$R_{near/far} = 2\,h$
ellipses open, area small:
field A.M. nonzero, small

$L = 2\lambda_0;\ \ L/\lambda_0 = 2$
$h = \lambda_0$
$R_{near/far} = 8\,h$
ellipses open, area larger:
field A.M. nonzero, larger

Friedrich Landstorfer. Energietransport im Nahfeld von Stabantennen [Energy flow in the near field of rod antennas]. Archiv für Elektronik und Übertragungstechnik 26(4):189-196 (April 1972). [in German]   Bild 11 [Figure 11]   [$R_{near/far}$ added]

Figure 11 in his paper shows, for three different ratios for monopole length to wavelength in air, what these ellipses look like on different lines showing the path of energy flow through the air around the rod antenna. I interpret these ellipses as signifying the presence of non-zero angular momentum, because they can represent the linear momentum density vector **g** as well as the Poynting vector **S** (because in air **g** and **S** are proportional).

The larger the area of the ellipse, the larger is the value of the angular momentum (A.M.). Where there is only a straight line instead of an ellipse, the field A.M. has shrunk to zero.

I have added to Landstorfer's Figure 11 the boundary between the near and far fields, according to the usual equation used by electrical engineers. It is shown as R in the upper and middle diagrams. (It is missing from the lower diagram because, being equal to 8 h, it would be far off the diagram.)

In Landstorfer's upper illustration, where the wavelength is larger than the antenna length, there is hardly any angular momentum present (the ellipses have a small area). The non-zero A.M. is present in the vicinity of the boundary and extends out into the far field: at distances greater than R. Close to the antenna in the near field, the A.M. is virtually zero (ellipses are straight lines).

This is in contrast to the middle and lower diagrams, where the region of non-zero A.M. appears to be confined to the near field. The middle diagram shows the field around a half-wave dipole antenna; the lower diagram illustrates the field when the wavelength is smaller than the antenna length (that is, for higher frequencies than that in the middle diagram). The middle and lower diagrams show the fields around *real* rod antennas. The highest A.M. tends to be present in the lower diagram, both along the ground plane and near the tip of the antenna.

This angular momentum has nothing to do with the photon spin, because it has nothing to do with the polarization of the far field radiation. Since this angular momentum in the near field of an RF transmitter cannot possibly be spin angular momentum, it must be orbital angular momentum.

Because the far field radiation from a rod antenna is linearly polarized, the spin angular momentum of the field around a rod antenna is everywhere zero. The ***only*** non-zero angular momentum in the electromagnetic field around a rod antenna is that in the near field of the antenna: the orbital angular momentum that is represented by the open ellipses displayed in Figure 11 of the 1972 paper by Friedrich Landstorfer.

The non-zero local orbital angular momentum of the near field of a rod antenna is undoubtedly the explanation for the near field health hazard in the vicinity of such transmitters that radio engineers recognized the existence of over half a century ago!

The equation for the volume density of force experienced by charges and currents within an infinitesimal volume of space, as a result of electric and magnetic fields originating outside that volume, is

$$\mathbf{f} = \partial\mathbf{g}/\partial t - \nabla \cdot \mathbf{T}$$

where it is important to notice that **f** depends not on **g**, but on its partial derivative with respect to time, $\partial\mathbf{g}/\partial t$. Because **g** is proportional to the Poynting vector **S**, $\partial\mathbf{g}/\partial t$ is proportional to $\partial\mathbf{S}/\partial t$.

This means that, in Landstorfer's diagrams of the ellipse traced by the Poynting vector, $\partial\mathbf{g}/\partial t$ and $\partial\mathbf{S}/\partial t$ would be represented by tangent lines to the ellipse. As time passes, the tip of the Poynting vector moves around the ellipse and a tangent line to the ellipse at the tip of the Poynting vector slides along the ellipse. If its length is the magnitude of either $\partial\mathbf{S}/\partial t$ or $\partial\mathbf{g}/\partial t$, this tangent line represents the time rate of change of that vector (**S** or **g**).

Obviously, when the tip of the Poynting vector has traced out the complete ellipse, the vector representing its time derivative has also returned to its starting point on the ellipse, which means that $\partial\mathbf{S}/\partial t$ (and therefore $\partial\mathbf{g}/\partial t$) has undergone one complete rotation thorough 360°. This rotation of the vector **g**, representing the momentum density of the electromagnetic field, is how we know that the ellipses that Landstorfer illustrated in his paper published in 1972 represent ***angular momentum*** of the electromagnetic field: linear momentum **g** continually rotating.

The volume density of torque τ experienced by matter exposed to a field having non-zero angular momentum is

$$\tau = \mathbf{r} \times \mathbf{f} = \mathbf{r} \times \partial\mathbf{g}/\partial t - \mathbf{r} \times \nabla \cdot \mathbf{T}.$$

No attempt at torque calculation is presented here.

A controlled laboratory experiment was done on mice a decade ago in which the mice were exposed to the microwave field of a monopole antenna mounted on a conducting plane, to simulate a dipole antenna. This was a blinded trial using a strain of transgenic mice that express an activated *Pim-1* oncogene in their lymphoid cells and therefore spontaneously develop lymphomas to an incidence of about 15% by the age of 18 months. The purpose of the experiment was to determine whether long-term exposure to pulse-modulated RF fields similar to those used in digital mobile telecommunications would increase the incidence of lymphomas in these mice.

Michael H. Repacholi, Antony Basten, Val Gebski, Denise Noonan, John Finnie & Alan W. Harris.
Lymphomas in Eμ-*Pim1* Transgenic Mice Exposed to Pulsed 900 MHz Electromagnetic Fields.
Radiation Research 147(5):631-640 (May 1997).

The findings from this experiment were:

> "Lymphoma risk was found to be significantly higher in the exposed mice than in the controls (OR = 2.4, P=0.006, 95% CI = 1.3 – 4.5)"

The lymphoma risk was approximately doubled by the pulsed microwave exposure.

A claim has subsequently been made that an effort to confirm this finding was unsuccessful; however, this claim is false because the alleged effort to confirm failed to replicate this experiment in many respects. Also, *other* experiments carried out under different conditions have confirmed the carcinogenic character of microwave radiation.

The published report of the Repacholi experiment claims that the mice were exposed in the *far field* of the antenna. Had the exposure been to a *continuous* 900 MHz field around the monopole antenna in the experiment, this claim would be correct. The antenna used was a quarter-wave monopole for 900 MHz; the monopole length $h = 0.5 \times 165$ mm, so the dipole length was L =165 mm (the ratio $L/\lambda_0 = \frac{1}{2}$). The formula for the boundary between near and far field, valid at the conducting plane, gives:

$$R_{near/far}\ (900\ \text{MHz}) = 2\ L\ (L/\lambda_0 = \tfrac{1}{2}) = L = 165\ \text{mm}.$$

The mice were exposed in cages that were located 650 mm from the antenna: a distance almost 4 times $R_{near/far}$ for 900 MHz. So the mice were indeed in the *far field* of this antenna for 0.9 GHz.

But the field was *pulsed*, not continuous! So there were *other frequencies* present (the intensity of which can be calculated by doing a Fourier transform of the pulsed signal used). The mice were in the *near field* for the fourth and all higher harmonics!

Harmonic	Frequency	Distance from Antenna to Far Field Boundary	
Fundamental	0.9 GHz	$R_{near/far}$ (900 MHz) =	165 mm
2^{nd}	1.8 GHz	$R_{near/far}$ (1800 MHz) =	330 mm
4^{th}	3.6 GHz	$R_{near/far}$ (3600 MHz) =	660 mm
8^{th}	7.2 GHz	$R_{near/far}$ (7200 MHz) =	1320 mm

The center of the cages of the exposed mice was 650 mm from the antenna, meaning that these mice were in the *near field* for the 4^{th} and all higher harmonics! They experienced a *near-field* exposure at these higher frequencies. So they were exposed to fields with *non-zero angular momentum* at harmonics $\geq$ the 4^{th}.

The hazard to health in the near field of a microwave transmitter that electrical engineers were aware of half a century ago results from the presence in the near field of ***non-zero angular momentum*** of that field.

Now I show that one health effect of the exposure of living tissue to a microwave field having non-zero angular momentum is the formation of tumors, including those that are carcinogenic.

The highest-quality epidemiological studies appear to be those reported by Lennart Hardell and colleagues, as their studies have large numbers of cellular telephone users and cover a substantial length of time. Hardell *et al.* have found evidence of an elevated risk of brain tumors among cellular phone users, whose brains are exposed to the *near field* of the antenna in the handset of the cellular phone used—and therefore presumably to fields having non-zero angular momentum.

L. Hardell, K. H. Mild & M. Carlberg. Further aspects on cellular and cordless telephones and brain tumours. International Journal of Oncology 22(2):399-407 (Feb. 2003).

K. Hansson Mild, L. Hardell, M. Kundi & M. O. Mattson. Mobile telephones and cancer: Is there really no evidence of an association? International Journal of Molecular Medicine 12(1):67-72 (July 2003).

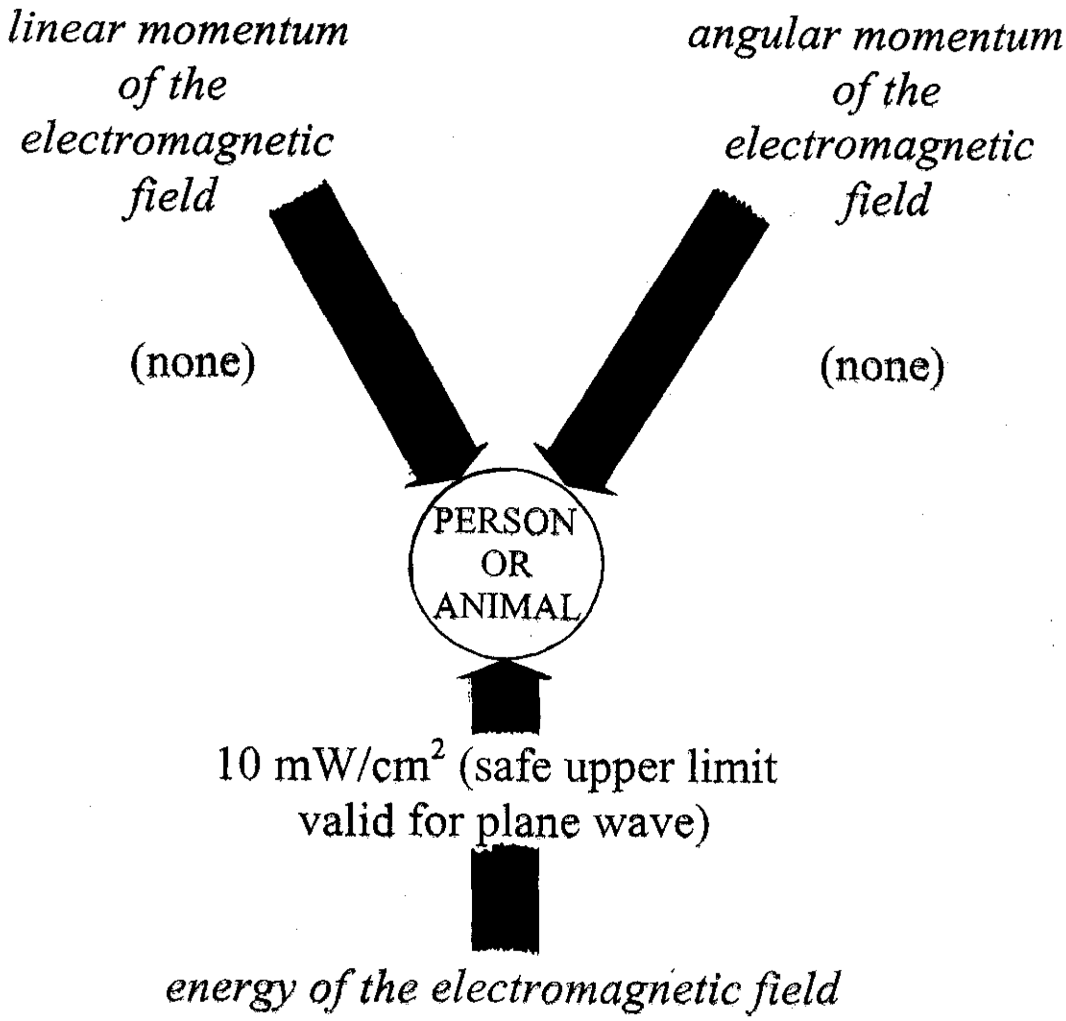
M. Kundi, K. Mild, L. Hardell & M. O. Mattsson. Mobile telephones and cancer—a review of epidemiological evidence. Journal of Toxicology and Environmental Health, Part B, Critical Reviews 7(5):351-384 (Sept.-Oct. 2004).

One may therefore conclude that long-term exposure to a microwave field having non-zero orbital angular momentum increases the risk of developing malignancies and tumors of all kinds.

This diagram shows what currently exists

in the way of safe limits

(this is strictly valid only for a plane wave).



This diagram shows that existing "safe limits" are

inadequate to provide complete health protection

because momentum transfer is totally uncontrolled!